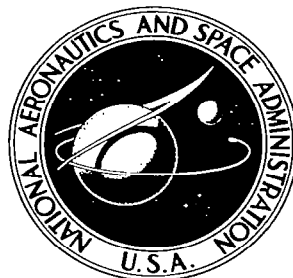


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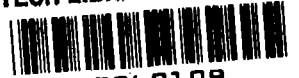
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**THE DESIGN, FABRICATION AND
FEASIBILITY TESTING OF A PROTOTYPE
AIRBORNE RESPIRATION ANALYZER**

by R. K. Breeze and G. W. Campbell

Prepared by
NORTH AMERICAN AVIATION, INC.
Los Angeles, Calif.
for Flight Research Center



THE DESIGN, FABRICATION AND FEASIBILITY TESTING OF A
PROTOTYPE AIRBORNE RESPIRATION ANALYZER

By R. K. Breeze and G. W. Campbell

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Prepared under Contract No. NAS 4-966 by
NORTH AMERICAN AVIATION, INC.
Los Angeles, Calif.

for Flight Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This document presents the results of the North American Aviation, Inc., Los Angeles Division's feasibility study of a prototype airborne respiration analyzer. The program was conducted over a period of five and one-half months under NASA Contract NAS4-966 and was sponsored by the NASA Flight Research Center, Edwards Air Force Base. Beckman Instruments, Inc. was a Subcontractor to North American Aviation, Inc. (NAA-LAD) in the feasibility study effort.

The purpose of the present program was to design, fabricate, and test a prototype airborne respiratory analyzer for feasibility. Feasibility concerns the capability of the analyzer to measure certain physiological functions such as P_{O_2} , P_{CO_2} , temperature, and respiratory mass flow rate accurately enough that oxygen consumption can be calculated within an overall accuracy of ± 10 percent.

The basic technical approach was outlined by the NASA (Dr. James Roman and Mr. Lewis Carpenter) as was the basic overall design configuration of the final prototype. The authors gratefully acknowledge the contributions of Paul Nielsen, NAA Laboratory Engineer, Verne Friedel, Laboratory Technician, also subject-observers R. Hart and R. Lepper. Acknowledgement is also given to test subjects Lynn Briley, R. Minner, W. Adams, and D. Manglesdorf of the NAA Life Sciences Group. Physiologists J. Raeke and M. Goldberg were especially helpful in the areas of laboratory test equipment and with advice and assistance in testing the human subjects.

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LIST OF SYMBOLS

F	mol fraction, dimensionless
\dot{m}	mass flowrate, lbs/min
M	molecular weight, dimensionless
P	partial pressure, mm Hg
R, R.Q.	respiratory quotient, dimensionless
V	volume, liters
\dot{V}	volume flowrate and volume uptake, liters/min
\dot{u}	mass uptake, lbs/min
Δ	difference

Subscripts

CO ₂	carbon dioxide
d	discharge
E, 2, out	expired
H ₂ O	water vapor
in, 1	inspired
N ₂	nitrogen
O ₂	oxygen
T	total

INTRODUCTION

The need for a device which can be used to monitor the respiratory processes and oxygen uptake of a highly stressed air or space crew member is clearly recognized by aeromedical personnel. This need has resulted in several NASA contracts to study and develop techniques, sensors, and systems to accomplish these measurements in the flight environment since clinical techniques were not compatible with airborne use under transient conditions.

NASA Contract NAS4-367 (Reference 2) was initiated for the purpose of developing to prototype status certain respiratory sensors and to test these sensors under various environmental conditions with human subjects. Under Phase I of that program a prototype sensor was assembled which utilized a Beckman Instruments, Inc. P_{O_2} , P_{CO_2} , P_T , and temperature sensor and NASA-supplied Technology, Inc. mass flowmeters. During testing under sea level and altitude conditions several inherent errors became apparent with regard to the determination of oxygen consumption. However, it required the efforts of a Phase II program with an analytical approach to the thermodynamic and physical characteristics of the system in order to pin-point the basic problems and determine the magnitude of possible errors. The results of the Phase II efforts were critically examined by Dr. J. Roman of the NASA Flight Research Center at Edwards Air Force Base. At his recommendation, several concept changes were made and further error analysis and system comparisons were conducted under Contract NAS4-876 (Reference 3). The results of these studies encouraged the development undertaken in the present program.

The respiratory analyzer design described herein minimizes the inherently large errors associated with measuring small differences in large quantities. Previous attempts to measure \dot{V}_{O_2} inhaled and \dot{V}_{O_2} exhaled by difference techniques in both flow metering and partial pressure sensing resulted in very large errors. The present system eliminates the need for taking flow differences by utilizing the inert diluent gas as a measure of volumetric change between inhalation and exhalation according to the

following equation:

$$\dot{V}_{O_2} = \left[F_{ECO_2} - \frac{F_{EN_2}}{F_{IN_2}} F_{EO_2} \right] \dot{V}_E \quad (1)$$

The errors in measuring the difference between inhaled and exhaled P_{O_2} are minimized by using a single sensor to determine both values thus eliminating the need for extreme accuracy in absolute partial pressure values.

The principle tasks covered by this program as given by the Work Statement are as follows:

1. Prove experimentally the feasibility of single sensor O_2 sampling.
2. Design system, assuming perfect input and output mixing.
3. Build and test system, using different levels of steady-state input P_{O_2} , and large, easily constructed mixing chambers, accepting the inevitably long time constant associated with such chambers.
4. Present the results of tests of this device to FRC, including spirometer and/or meteorological balloon sampling checks of the method at altitudes of: SL, 5000, 10,000, 15,000-ft pressure altitude.
5. Design and test small mixing chambers, and determine the minimum required size for ± 1 percent P_{O_2} variation over one entire exhalation or inhalation using a NASA-furnished regulator for input testing.

ANALYZER SYSTEM DESIGN

BACKGROUND

The basic principles of the analyzer system design were established as the result of NASA Contracts NAS4-876 (Reference 3) and NAS4-367 (Reference 2). The work of Reference (2) consisted of an error analysis of an earlier system design and was very helpful in determining sensor characteristics and in identifying problem areas and techniques which must be avoided. A schematic of this system and a summary curve of the error analysis are shown in figures 1 and 2. The extreme sensitivity of oxygen uptake to mass flow measurement accuracy is apparent. When the problems of measuring a pulsatile flow are considered, the inherent difficulties become even more striking. Both oxygen partial pressure and total pressure accuracies are also seen to exert strong influence on oxygen uptake. These parameters, and particularly the total pressure, are, however, less susceptible to error in measurement.

The method suggested in Reference (3) offers considerable improvement in feasibility. A schematic of this system along with typical error analyses curves are shown in figure 3 through 6. The basic equation for determining oxygen uptake for this system is:

$$\dot{V}_{O_2} = \left[\left(\frac{P_{O_2 \text{ in}}}{P_T} \right) \left(\frac{P_T - P_{CO_2 \text{ out}} - P_{O_2 \text{ out}}}{P_T - P_{O_2 \text{ in}}} \right) - \left(\frac{P_{O_2 \text{ out}}}{P_T} \right) \right] \dot{V}_d \quad (2)$$

$$\text{where } P_{N_2 \text{ out}} = P_T - P_{CO_2 \text{ out}} - P_{O_2 \text{ out}}$$

$$\text{and } P_{N_2 \text{ in}} = P_T - P_{O_2 \text{ in}}$$

It may also be expressed in terms of oxygen mass uptake in the form:

$$\dot{U} \frac{M_{\text{out}}}{M_{O_2 \text{ in}} P_T} \left[P_{O_2 \text{ in}} - P_{O_2 \text{ out}} \frac{P_T - P_{O_2 \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2} - P_{H_2O \text{ out}}} \right] \dot{m}_{\text{in}} \quad (3)$$

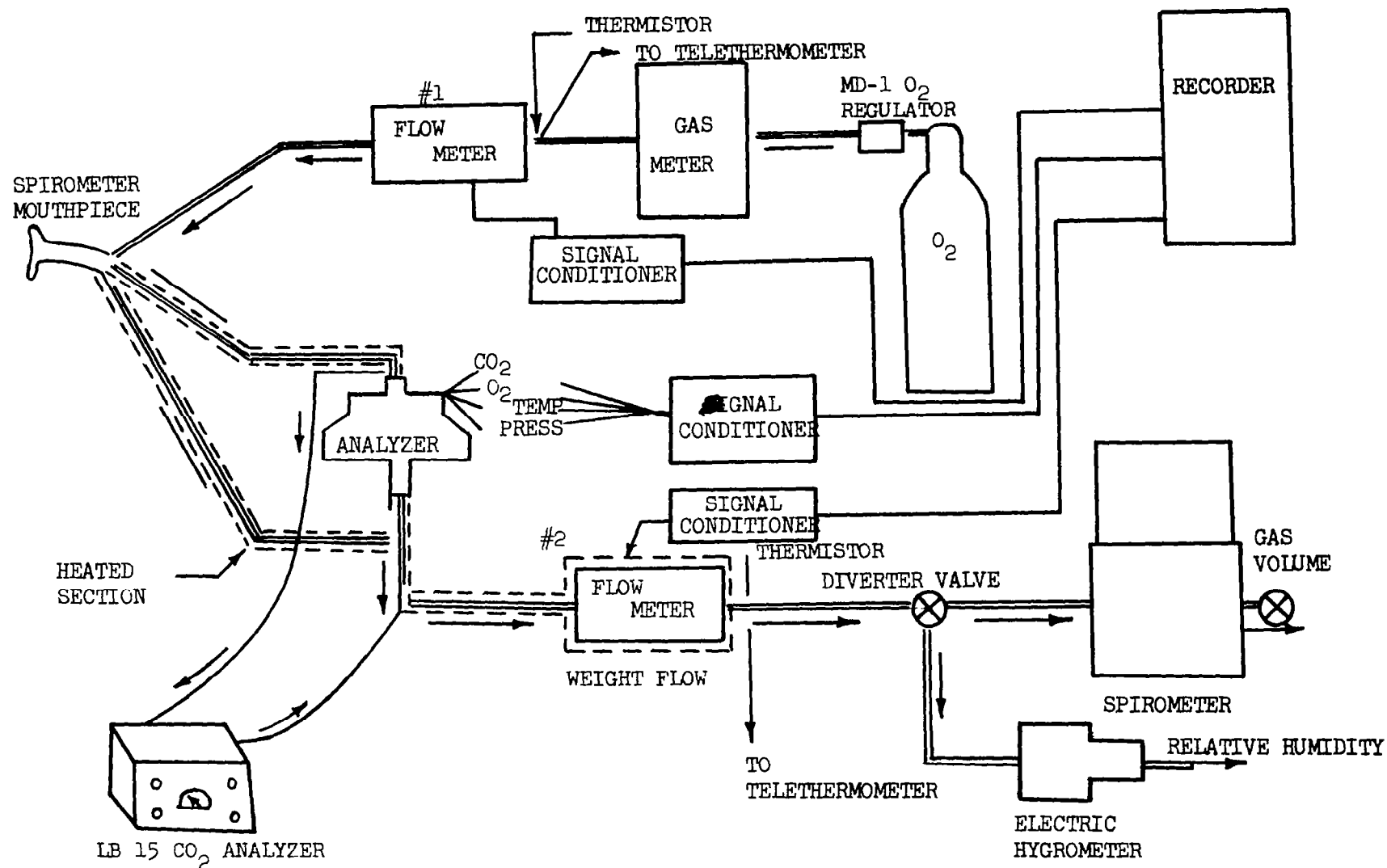


Figure 1. SCHEMATIC OF THE PROTOTYPE RESPIRATION ANALYZER SYSTEM SHOWN TO BE UNSATISFACTORY UNDER NAS⁴-367

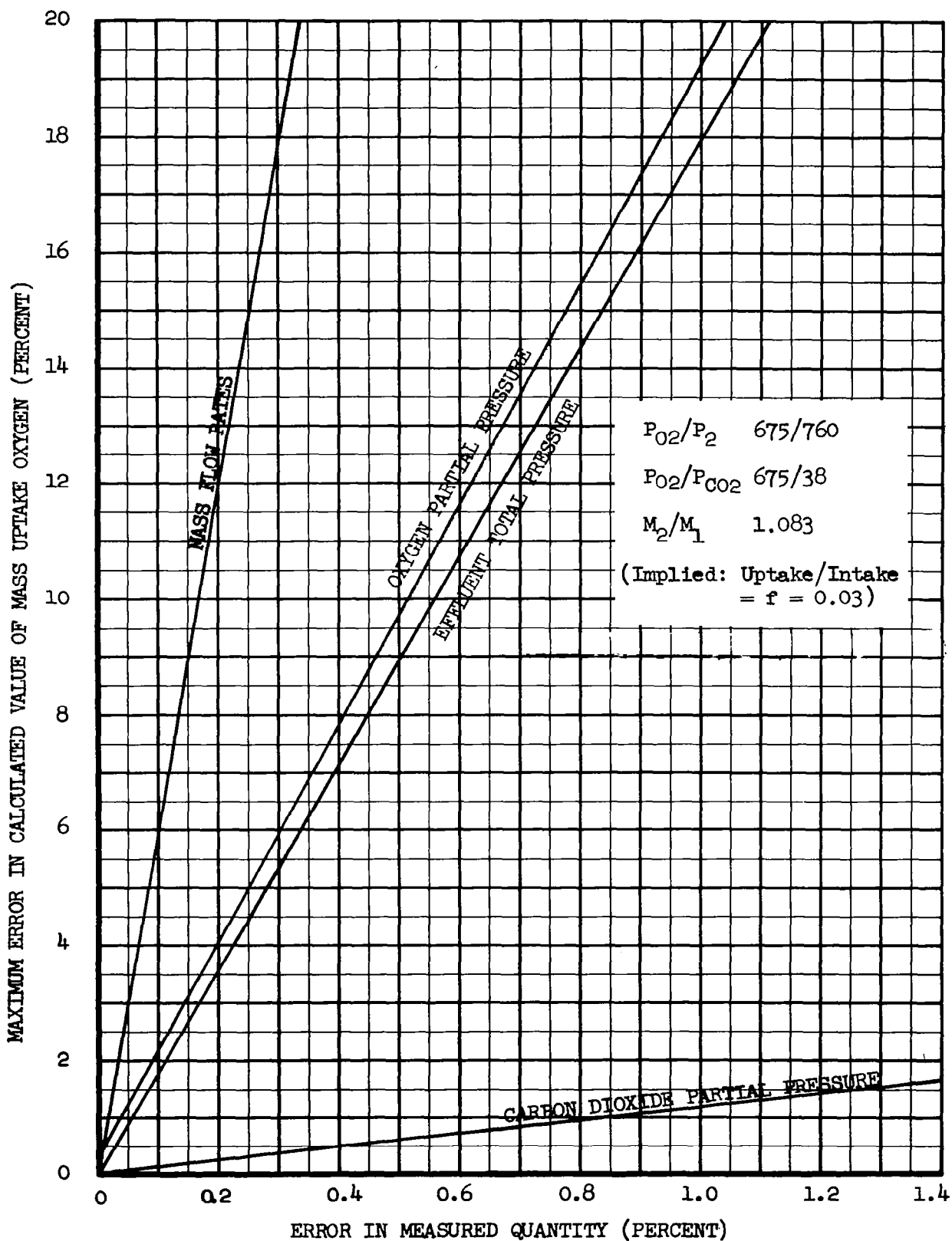


Figure 2. Error Analysis, Respiration Analyzer Unsatisfactory Configuration.

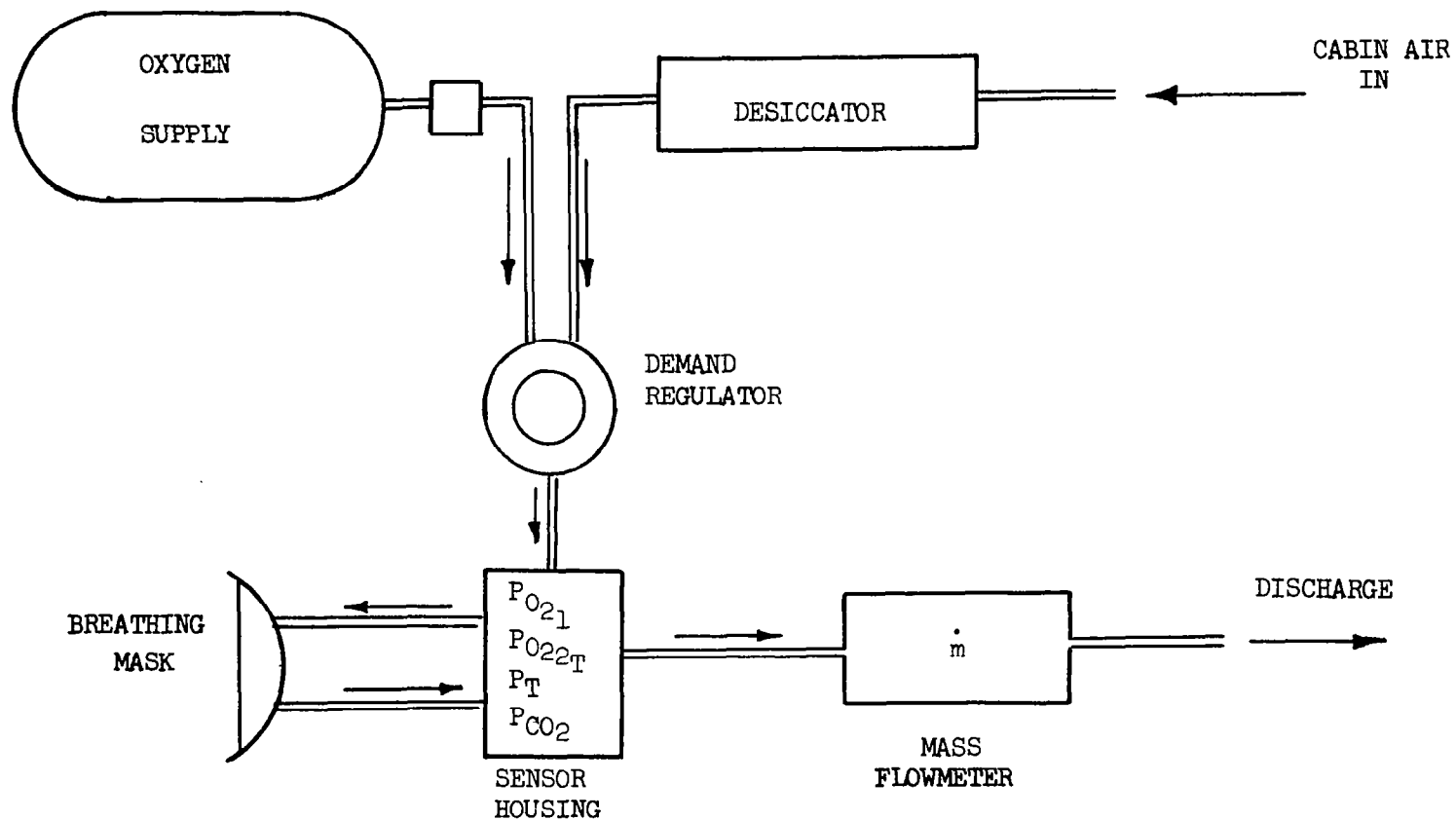


Figure 3. PRELIMINARY DIAGRAM OF RESPIRATION ANALYZER FROM REFERENCE 3

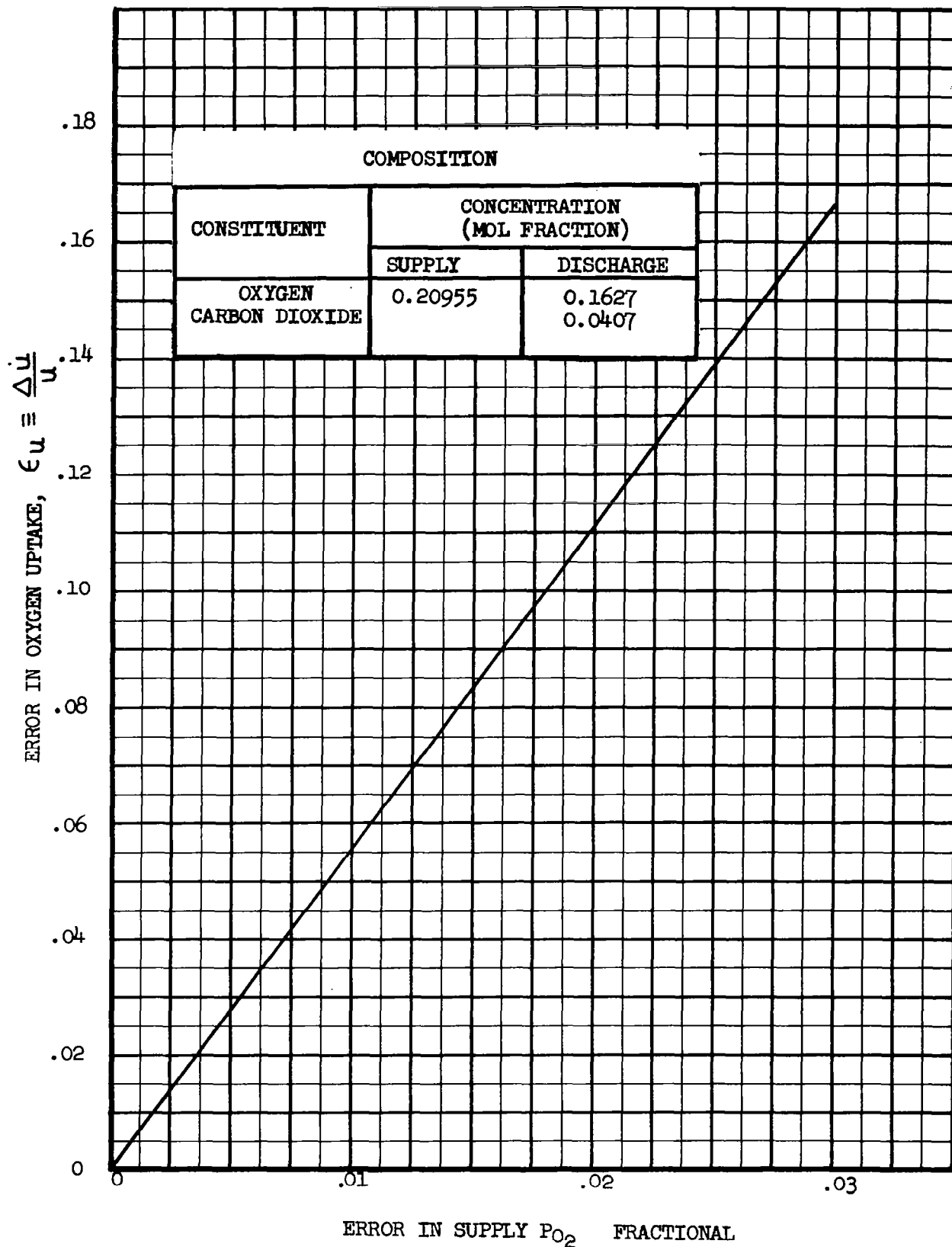


Figure 4. Effect of Error in Supply O_2 Partial Pressure Measurement

COMPOSITION

CONSTITUENT	CONCENTRATION (MOL FRACTION)	
	SUPPLY	DISCHARGE
OXYGEN	0.20955	0.1627
CARBON DIOXIDE		0.0407

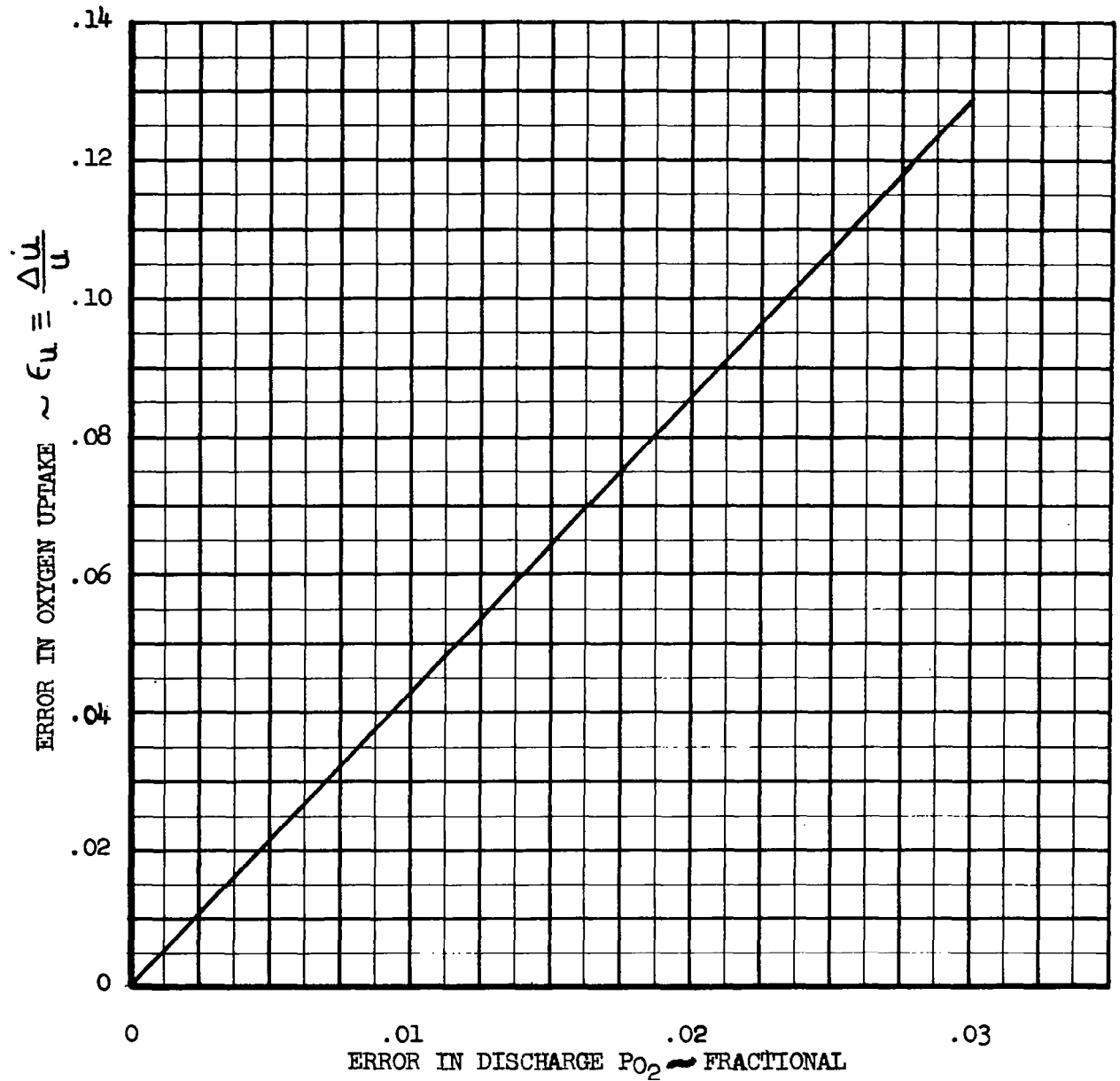
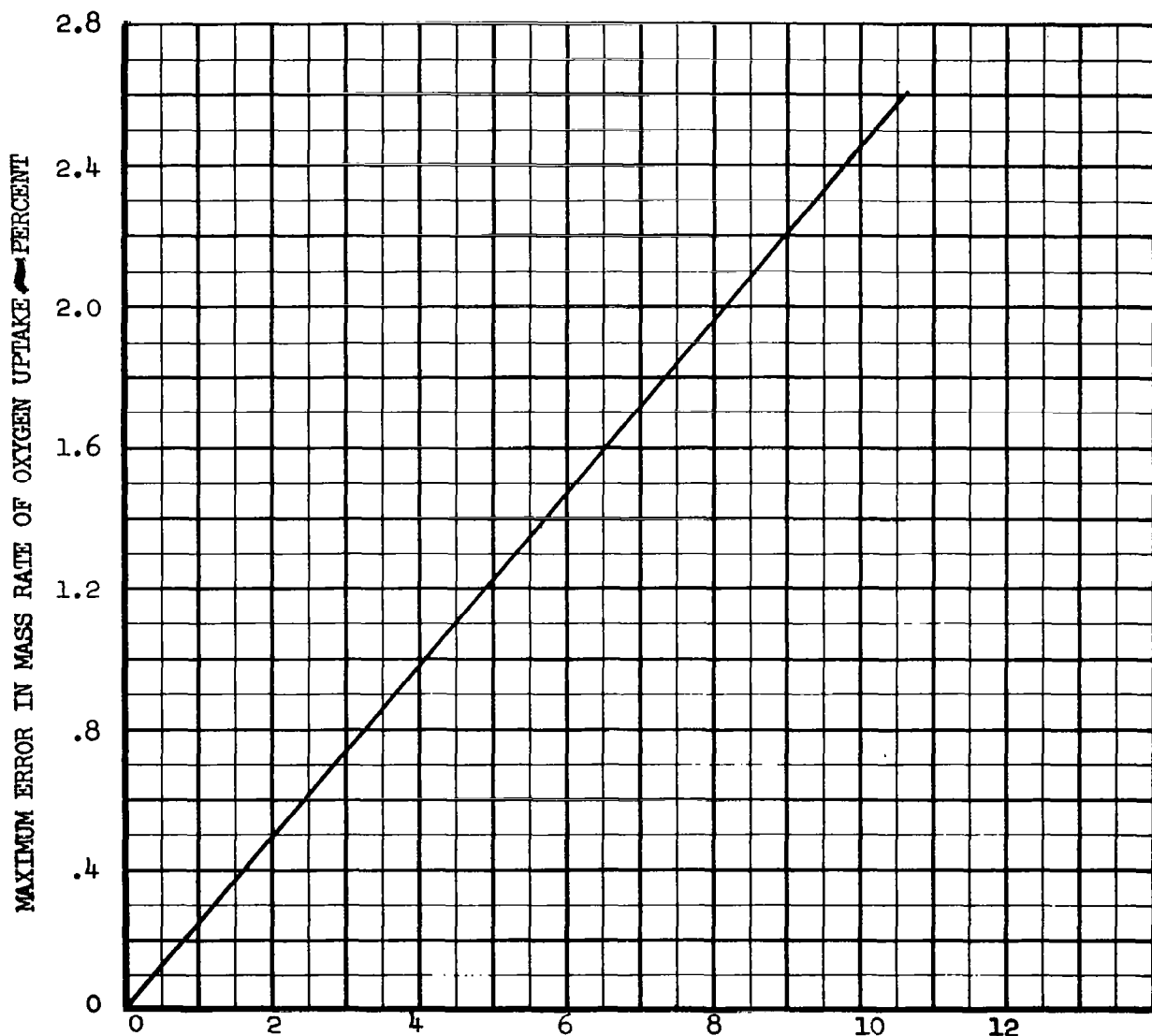


Figure 5. Effect of Error in Discharge O_2 Partial Pressure Measurement

COMPOSITION

CONSTITUENT	CONCENTRATION (MOL FRACTION)	
	SUPPLY	DISCHARGE
OXYGEN	0.20955	0.1627
CARBON DIOXIDE		0.0407



ERROR IN MEASUREMENT OF DISCHARGE PARTIAL PRESSURE OF CARBON DIOXIDE ~ PERCENT

Figure 6. Effect of Error in CO₂ Partial Pressure Measurement on Oxygen Uptake Rate

Here it can be seen that the sensitivity of oxygen uptake to mass flow metering has been reduced to approximately 1/60th of that in the previous example and that the accuracy requirements for oxygen partial pressure sensing are also appreciably alleviated. In spite of these decreased sensitivities, however, the accumulative errors could be undesirably large unless further improvements could be made, particularly in oxygen partial pressure sensing. This problem was examined by Dr. Roman of the NASA Flight Research Center and recommendations were made to design a system in which both the inhaled and exhaled air be sampled by the same sensor in order to eliminate the need for extreme accuracies in the absolute values of oxygen partial pressure. It was further recommended that the device sample quasi-steady-state gas composition rather than the rapidly fluctuating compositions of unmixed inspiratory or expiratory products. This was to be accomplished by placing mixing chambers in the supply and discharge lines from the mask which would be capable of keeping breath-by-breath fluctuations of P_{O_2} and P_{CO_2} to ± 1 percent or less, as measured at the output of the sensors. The inhaled and exhaled gasses were to be monitored alternately.

PRELIMINARY SYSTEM CONCEPTS

As a result of the previous program failures to prove feasibility with the system design concept utilized, the first task of the present program in light of the error analysis was to design a system concept containing desired features discussed in preceding paragraphs. Many trade-off studies were made to determine a design of a respiration analyzer which would have sufficiently good characteristics to be fabricated for test and further development. Of all the basic designs evaluated, two methods evolved which typified the possible designs which utilize single sensor P_{O_2} measurement. These systems are shown schematically in figures 7 and 8.

The system shown in figure 7 processes all inspired and expired gases. The valves in the valve housing, which also contains all the sensors except the P_{CO_2} unit, are actuated by the subjects breathing forces. The P_{O_2} sensor sees inspired and expired gases alternately on a breath-by-breath basis, and, therefore, requires a fast response to changing

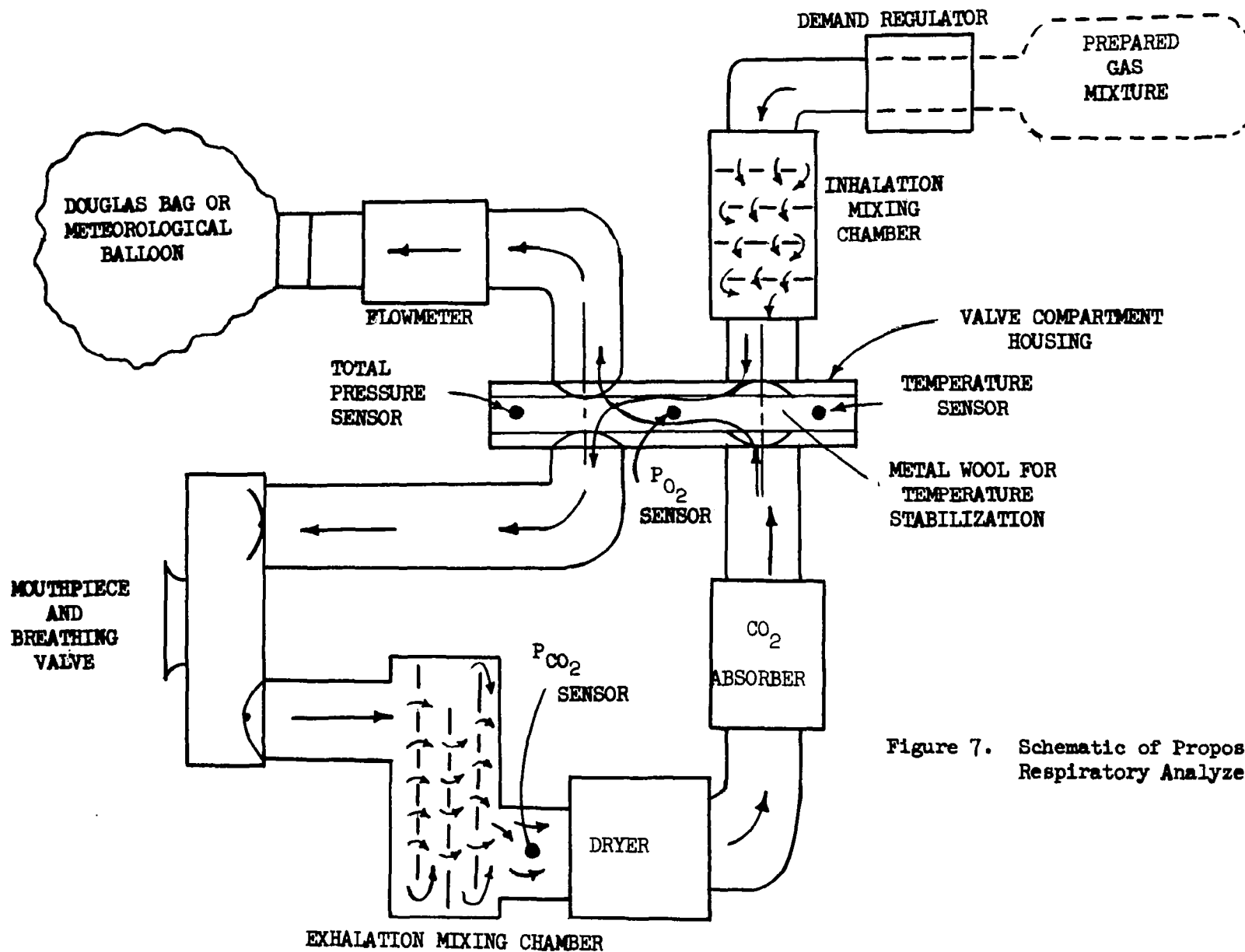


Figure 7. Schematic of Proposed Respiratory Analyzer

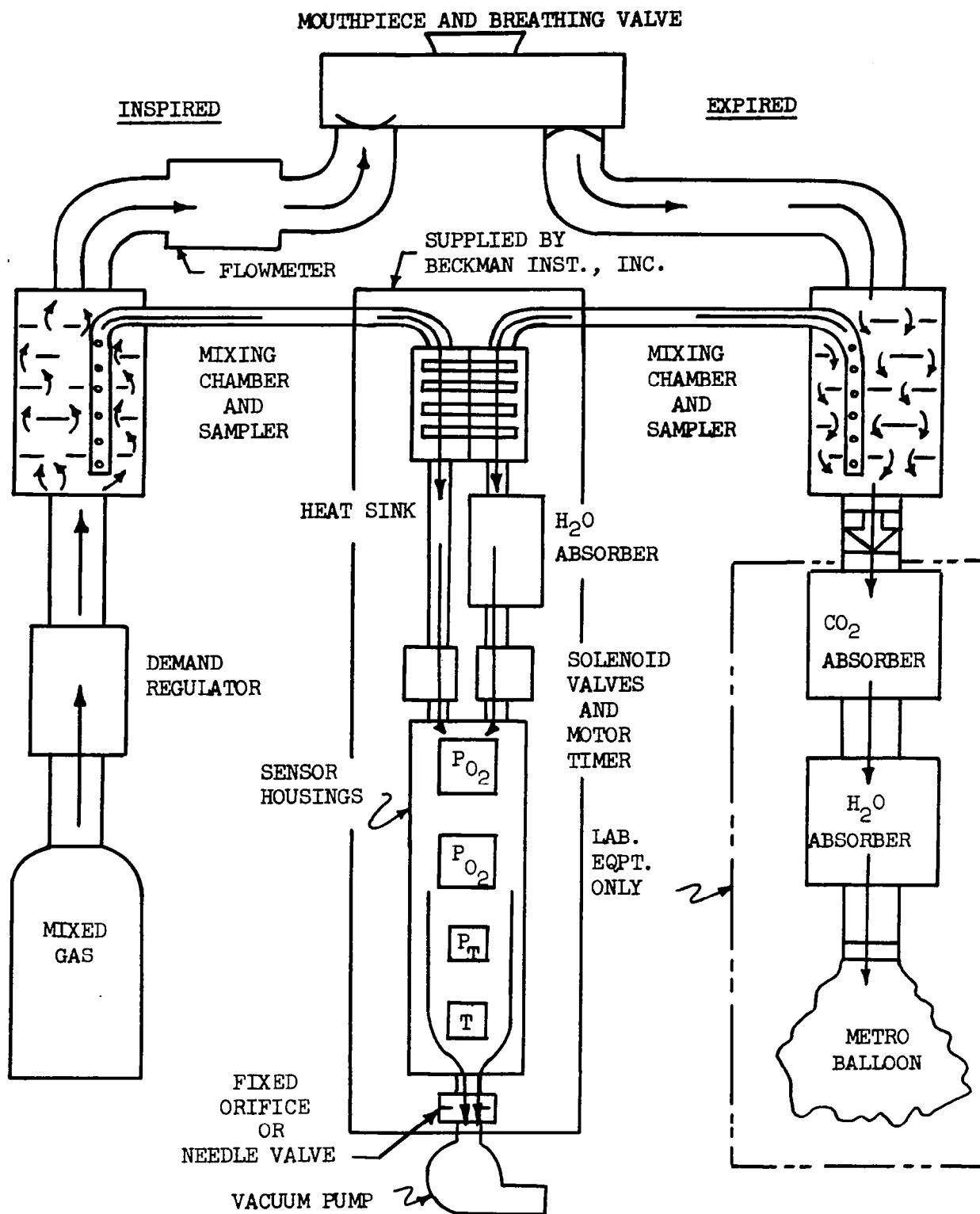


Figure 8. Schematic of Respiratory Analyzer -- Sampling System

composition. Since the flowmeter is located downstream (expired side) the water must be absorbed in order to know the condition of the air and since absorbents of water also absorb some CO_2 , then all CO_2 must be absorbed in order to determine the quantity of the gaseous constituents. In another system design the flowmeter could be located upstream (inspired side) and thus eliminate the problem of moisture getting into the flowmeter. There are certain inherent problems with this system. The design is subject to high breathing resistance because of the valves and absorbers. Also, CO_2 absorption in a flight system would be highly undesirable and the fast response requirement for the sensors could make satisfactory PO_2 sensing marginal. The system shown in figure 8 was selected as the most promising design, containing the most desirable features from many practical stand-points and will be discussed in the next section.

FINAL DESIGN CONCEPT

In the system shown in figure 8, only a small portion of the inspired or expired air is processed (from 100 to 200 cc/minute). The gas sample processing is separated from the breathing system insofar as the main ventilation path is concerned, such that the subject will not feel any large flow resistances. Flow resistances must be in accordance with figure 9. Extremely fast response times for the sensors are not required since the motor-timed solenoid valves will allow 30 seconds sensing of inspired and 30 seconds sensing of expired gases each minute of operation. An adjustable cam on the timing motor allows for changes in the timing sequence of the valves if desired. The mass flow rate of gases is measured on the inspired side so that there will be no moisture to distort the accuracy of the instrument. Internal volume in the area of the sensors was kept to a minimum by careful design of the sensor housing and proper location of the solenoid valves.

Referring again to figure 8, the inspired air can be supplied from a prepared mixed gas or a diluter-demand regulator. In actual aircraft use, however, only the diluter-demand regulator will be incorporated. The inspired air then passes into a mixing chamber capable of mixing the gas such that the breath-to-breath fluctuations in PO_2 are maintained within

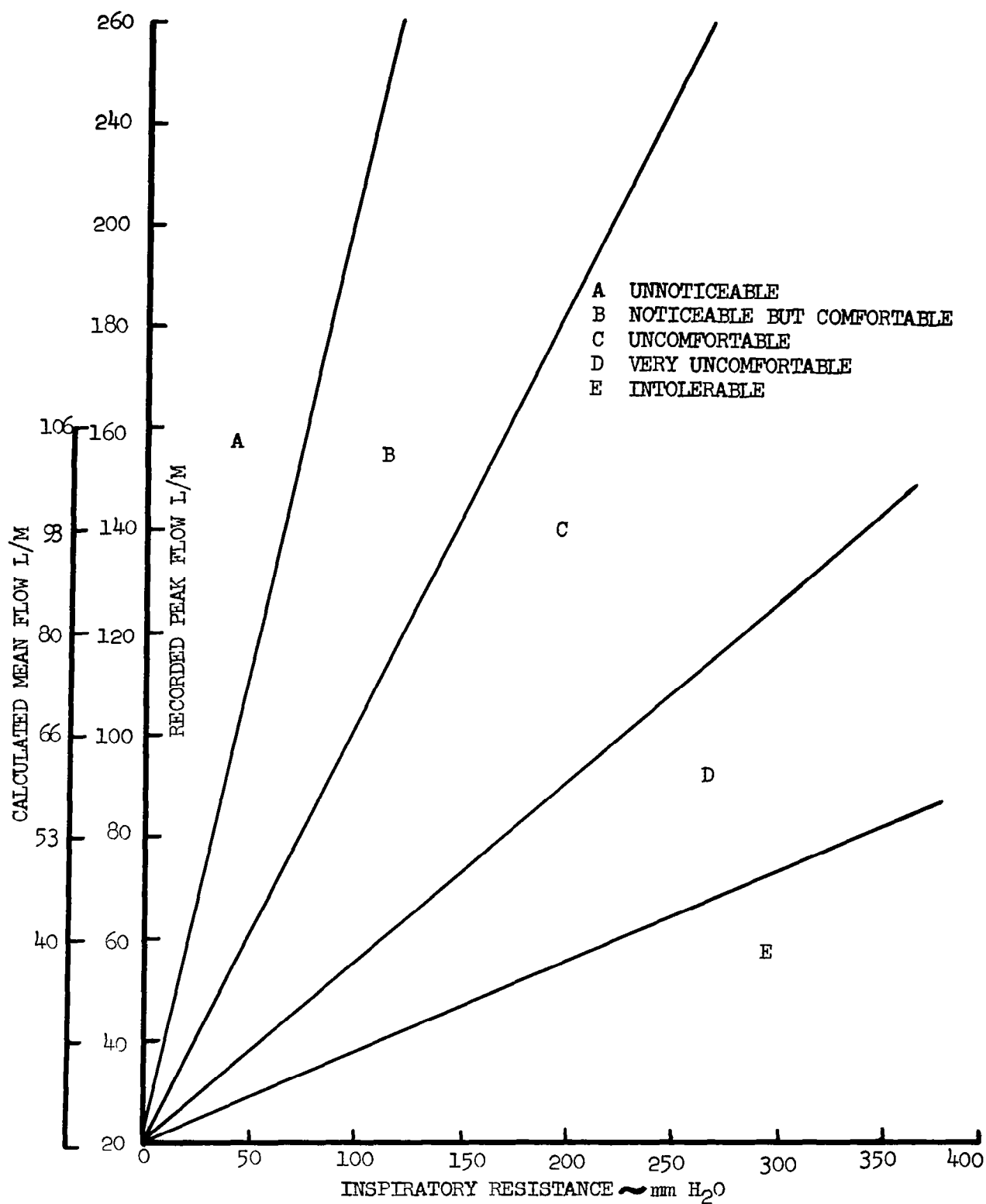


Figure 9. Subjective Classification of Inspiratory Resistance at Various Flow Rates.

±1 percent. The gas then passes through a flowmeter (Technology, Inc. pneumotachometer) whose output is recorded as a breath-by-breath trace. The gas then passes through the breathing valve in the mouthpiece. On the expiration side, the exhaled gases pass through a breathing valve and into a similar mixing chamber. In actual flight use, the discharge from the mixing chamber would be dumped into the cockpit. In the test setup, however, the expired gases were collected for treatment and analysis. Several methods of treating and analyzing the gases have been employed throughout this program and are discussed elsewhere in this report. Analysis of the inspired and expired gases are accomplished by alternately withdrawing samples from the two mixing chambers and passing them through the sensor housings where values of P_{O_2} , P_{CO_2} , P_T , and T are measured. The samples are withdrawn by means of a vacuum pump which maintains sonic flow across the annular orifice of a needle valve. In the final analyzer package a small rotameter is utilized to measure the sample flow. The gases from the sample chamber are first passed through a heat-sink type heat exchanger which assures that both sample streams are at the same temperature. The expired gas then passes through a chamber which was initially packed with a wicking material to absorb any free water which might be present in the expired gas. It was later found this was not necessary and the packing was removed. The gas is then passed through solenoid-actuated valves which alternately introduce inspired and expired gases to the sensors. The flow volume between the solenoid and the sensors is kept extremely small to minimize purging time between cycles. Sample flow rates were adjusted to between 100 and 200 cc's per minute. It was originally assumed that the expired breath would be continually cooled down as the flow passed through the lines, mixing chamber, and heat sink heat exchanger. Thus, the exhaled air which was essentially saturated would lose moisture by condensation through the entire process and would be saturated at the temperature of the sensor housing. During the testing, however, it was found that the heat rejection of the solenoid valves raised the temperature of the sensor housing and heat exchanger unit considerably above the temperature of the mixing chamber. It thus became necessary to compute the partial pressure of water on the basis of saturation at the mixing chamber temperature. The temperature sensor in the analyzer thus became superfluous since

it was not required for any of the other data reduction.

A preliminary specification was prepared for the monitoring system which was to be designed and constructed by Beckman. This design specification and miscellaneous information are shown below.

Miscellaneous Information

The monitoring system consists of the following:

- (1) Heat exchanger
- (2) Water droplet absorber
- (3) Solenoid valves (2)
- (4) P_{O_2} sensor system
- (5) P_{CO_2} sensor system
- (6) Air temperature sensor system
- (7) Total pressure sensor system
- (8) Needle valve and rotometer
- (9) Timer with adjustable cams
- (10) Analysis chamber
- (11) Enclosure, containing all the above

Figure 8 is a schematic representation of the complete analyzer. The blocked-in portion is to be furnished by Beckman, and will be mounted in a single enclosure.

This system will be used in a laboratory, but is a prototype for a flight unit. It will normally be used for periods of approximately 15 minutes.

Operation will consist of one-minute cycles, each cycle consisting of two definite periods; one period when inspired gases are being sampled, and the other period when expired gases are sampled.

A period will last a minimum of 15 seconds, but should be adjustable (i.e., typical periods might be 15 seconds/45 seconds, or 30 seconds/30 seconds).

The operating ambient temperature range will be 50°F to 110°F, while the gas temperature in the sample cell will probably hold around 80°F (due to the heat sink plus thermal insulation from ambient).

The instrument shall require a maximum of 13 seconds to respond 98 percent after switching sample gas (from inspired to expired gas or vice versa), which includes sample-cell purge time as well as sensor response times.

The sample cell temperature (excluding the IR CO₂ cell) must be below 98°F. (This can be adhered to even in 100°F ambients due to the cooling action of the inspired air, which will be kept below 98°F.)

All sensors should be calibrated within ±2 percent (±1 percent wherever possible). All outputs should be 0 - 5 volts dc, single ended. P_{O₂} will be ±1.0 percent of reading.

The system will be required to operate in environments from sea-level pressure to 15,000 ft simulated altitude (8.29 psi).

Because it is necessary to deliver the instrument by December 27, and it was felt that the IR CO₂ sensor could not be completed until January 31, North American agreed to accept an initial delivery by December 27 with an interim CO₂ monitor (the Monobeam). The IR CO₂ will be installed into the instrument when completed, and the instrument must be designed to accommodate it.

Specifications

1. Analyzer

Size	not specified
Weight	not specified
Pneumatic connections	3-2 inlet, 1 outlet; 1/8" tube fittings
Power	28v dc ±3v dc (115v 60 cycle may be utilized if absolutely necessary)
Electrical connections	(1) 5-way binding posts (2) for 28v dc power (2) 115v 60 line cord (optional)
Output connectors	3-circuit phone jacks
Controls	(1) front panel controls for all channels (2) power switch (3) circuit breaker (4) timer mode switch

2. P_{O₂} Channel

P _{O₂} range	0-500 mm Hg
Accuracy	±2% of reading (±1% at ±5°F temperature)
Temp. Range	60°F to 100°F
Response Time	95% response to a 50 mm Hg step change in 10 seconds

2. P_{O2} Channel (Continued)

Output	0-5v dc
Output Impedance	less than 1000 ohms
Power	+ 12v, - 6v dc
Linearity	±1% of full scale
Controls	Calib (span)

3. Temperature Channel

Temperature Range	50° - 100°F
Accuracy	±0.5°F
Response Time	98% Response to step change in 10 seconds (in moving air)
Linearity	Not specified (calibration curve will be supplied if nonlinearity exceeds 0.5°F)
Output	0-5v dc
Output Impedance	Less than 1000 ohms
Power	+ 12v, -6v dc
Controls	Calib (span); Zero 50°; Cal 100°; Cal; Operate

4. Pressure Channel

Pressure Range	0-20 psia
Accuracy	±2% of full scale
Response time	98% response is less than 1 second
Linearity	±1% of full scale
Output	0-5v dc
Output Impedance	less than 1000 ohms
Power	+ 20v dc; + 12v dc; - 6v dc
Controls	Calib (span) zero

5. IR CO₂ Channel

P _{CO2} Range	0-40 mm Hg P _{CO2}
Accuracy	±2% of full scale
Response Time	98% response to step change in less than 1 second, (exclusive of cell purge time)
Linearity	Not specified
Output	0-5v dc
Output Impedance	less than 1000 ohms
Power	Not specified
Controls	Calib (span) zero

TEST PROGRAM

TEST SETUP AND PROCEDURES

It may be well to note at this point that the primary purpose in these tests was not to collect physiological data, but to check the operational characteristics and accuracy of sensing of the system utilizing human subjects breathing into the system at different energy output levels. The system was arranged such that the effluent from the expiratory mixing chamber could be collected over an accurately known interval of the run, and the volume and composition compared to the averages of the dynamic readings obtained by the analyzer during this same interval of time.

During the course of the program several variations to the laboratory test setup and experimental procedures were tried utilizing both human subjects and a breathing machine. Some of the major changes are shown in the schematics, figures 10 through 13, where it may be seen that the changes were primarily with the laboratory method of collecting and determining the volume of expired gases and in the use of CO₂ and H₂O absorbers. Some changes were made for purpose of expediting the tests so that the subjects would not be required to spend long periods of time walking on the treadmill while sample analysis and volume checks were made. This was primarily the reason, early in the test program, for the change between figures 10 and 11. In this change, the gas meter was eliminated and the expired gases were collected in the spirometer directly. Utilizing figure 11, which was the test setup for most of the sea level runs prior to Run No. 20, a typical run was made after the system was warmed up, as follows:

1. The subject inserts the mouthpiece and begins breathing into system.
2. The sample shut-off valve is closed.
3. The analyzer is placed in "Timer Mode" to alternately sample inspired and expired gas.
4. The sample valve from the inspiratory mixing chamber or line is opened.

5. The three-way valve is closed and the spirometer is filled and purged by opening the outlet valve of the spirometer exhaust line.
6. After several purgings the spirometer is filled for a run at a given set of conditions for the subject.
7. The time is accurately noted by an impulse sent to the Offner Recorder when the three-way valve is switched to fill and when the impulse is cut off as the valve is switched to by-pass position.
8. The sample shut-off valve is opened and the sample valve in the inspired line is closed.
9. The analyzer is locked on "Inhale" position of the solenoid valves.
10. The spirometer is partially purged and the spirometer gases are sampled and the data recorded continuously.
11. The remainder of the spirometer gases are purged and a hygrometer reading taken of the humidity of the spirometer gases.

Periodically, before and after test runs, the accuracy of the P_{O_2} and P_{CO_2} sensors was checked utilizing prepared gas mixtures whose composition had been very accurately tested and noted. A more detailed description of these sensor calibrations and examples of the calibrations may be found in later sections of this report.

Several shortcomings in the system used to collect the discharge gas samples were noted during initial runs. It was found that at high work levels the 13.5 liter spirometer could collect only about a 1/2 to one-minute sample. This made the operation of the three-way valve difficult for the operator and magnified the effect of errors in timing, since valve opening and closing time could represent 3 or 4 percent of the sample interval. The large volume of the cannister used in processing the discharge gas meant that the sample actually collected in the spirometer did not correspond time-wise to the gas being monitored by the analyzer. The spirometer also has an inherent difficulty in that the gas being sampled is diluted with the mixture already present in the tare volume of the spirometer. Although the spirometer was purged several times using the subjects breath, any changes in respiration from purging to actual sampling

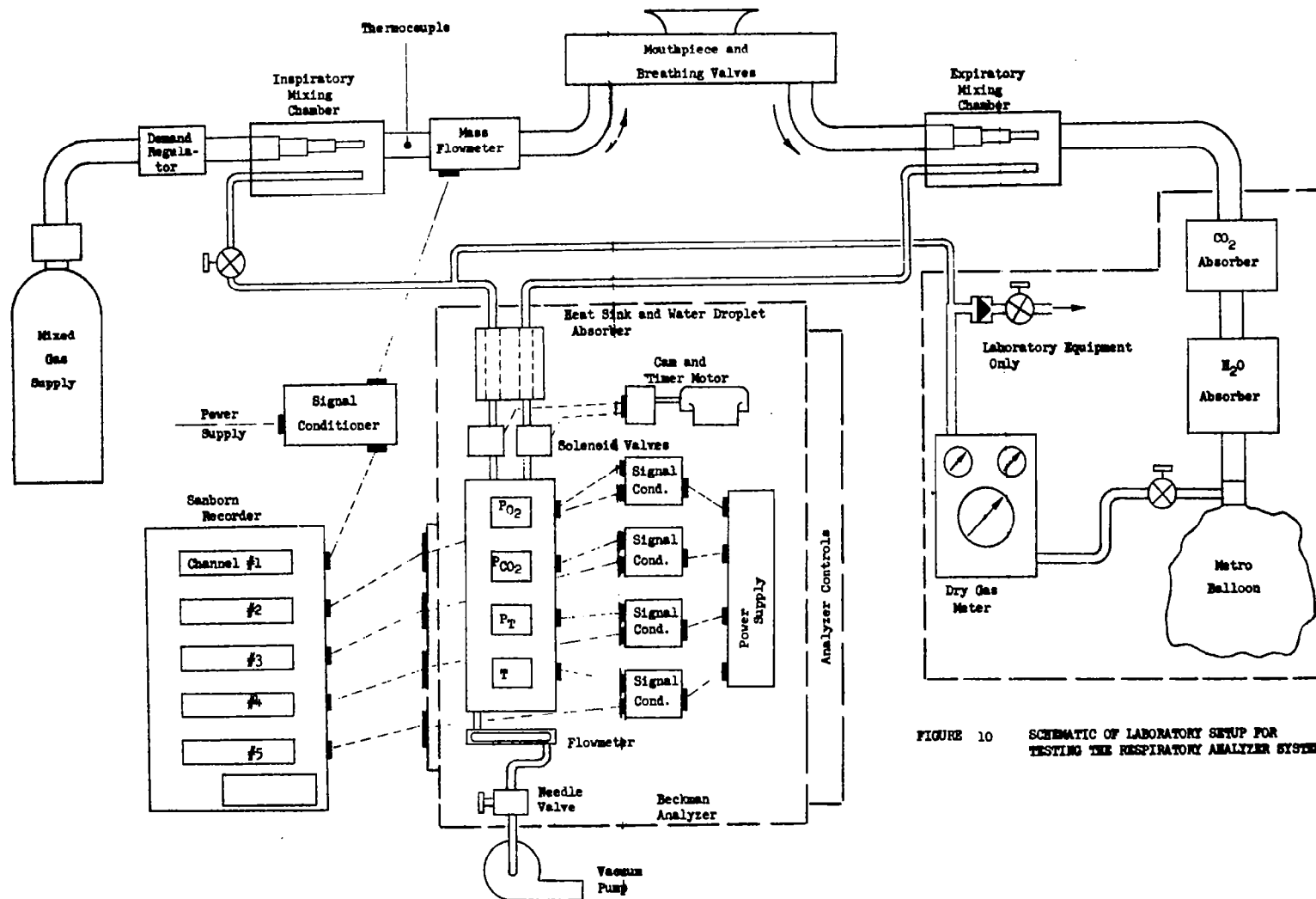


FIGURE 10 SCHEMATIC OF LABORATORY SETUP FOR TESTING THE RESPIRATORY ANALYZER SYSTEM

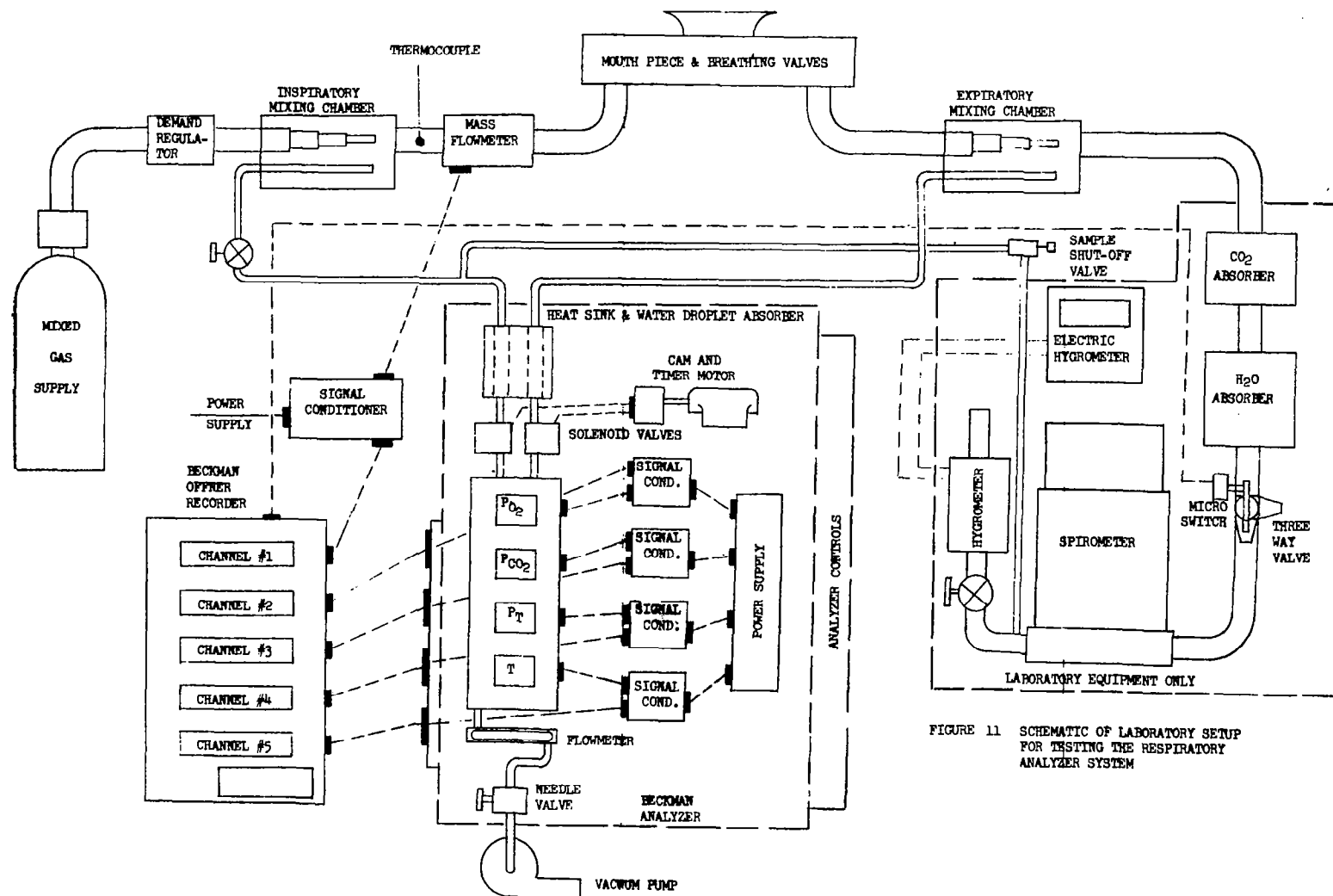


FIGURE 11 SCHEMATIC OF LABORATORY SETUP FOR TESTING THE RESPIRATORY ANALYZER SYSTEM

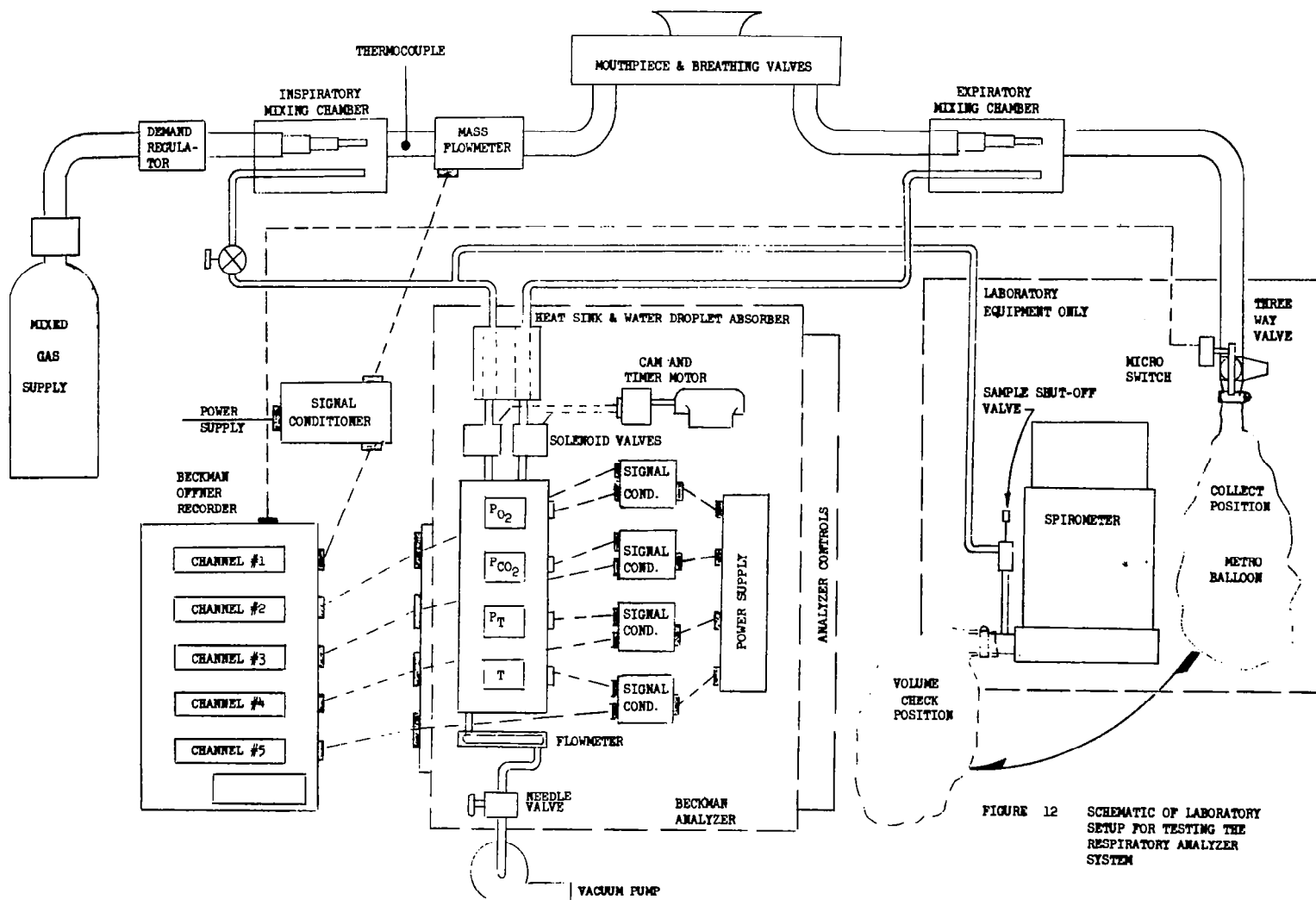


FIGURE 12 SCHEMATIC OF LABORATORY SETUP FOR TESTING THE RESPIRATORY ANALYZER SYSTEM

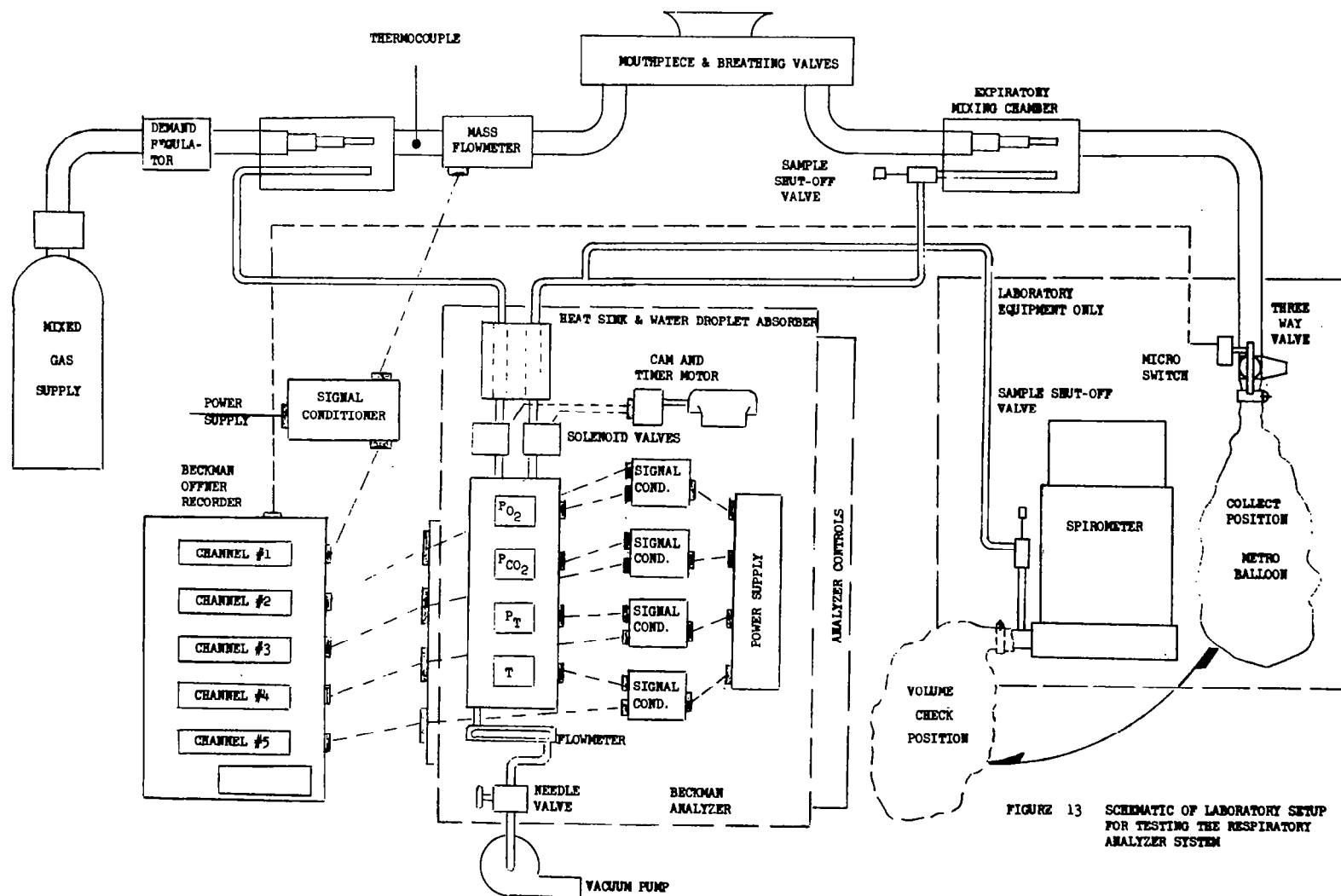


FIGURE 13 SCHEMATIC OF LABORATORY SETUP FOR TESTING THE RESPIRATORY ANALYZER SYSTEM

would introduce error. Also, the water used as a seal in the spirometer rehumidified the dried gases to some extent.

It was decided to reduce system volumes and eliminate both CO₂ and H₂O absorber canisters. The CO₂ which was no longer absorbed was simply measured during the sampling procedures. Advantages were gained in that less volume existed between the subject and the collection system. The expired gases were collected directly into a meteorological balloon. After a sufficient sample of expired gases (usually about 2 minutes) were collected the balloon would be disconnected from the three-way valve and connected to the spirometer inlet where the volume would be measured in one or more operations of the spirometer and a sample of this gas would be drawn through the analyzer sensing chamber for analysis of P_{O₂}, P_{CO₂}, etc. This method and procedure are shown schematically in figure 12. The change shown in the schematic, figure 13, was made in the sensing lines from the spirometer to the analyzer. Originally, the line for sampling gas from the spirometer wasteed into the inspiratory gas sensing line instead of the expiratory gas sensing line. This was changed after Run No. 26 when it was suspected that the sensing line valve was not closed tight on the previous run thus diluting the balloon sample with oxygen enriched air and causing an error in the results.

DEVELOPMENT OF EQUATIONS FOR DATA ANALYSIS

A convenient starting point for development of the relationship utilized in analyzing the data of these tests may be found in Reference (10), page 683, equations (8), (9), and (12), renumbered as shown below.

$$\dot{V}_{CO_2} = \left[F_{ECO_2} - \frac{F_{EN_2}}{F_{IN_2}} F_{ICO_2} \right] \dot{V}_E \quad (4) \text{ where}$$

$$\dot{V}_{O_2} = \left[F_{IO_2} \frac{F_{EN_2}}{F_{IN_2}} - F_{EO_2} \right] \dot{V}_E \quad (5)$$

$$R = \frac{F_{ECO_2} - F_{ICO_2} \frac{F_{EN_2}}{F_{IN_2}}}{F_{IO_2} \frac{F_{EN_2}}{F_{INL}} - F_{EO_2}} \quad (6)$$

It should be noted that when no nitrogen (or other physiologically inert) gas is present, the equations become degenerate. Furthermore, it should be emphasized that all the subsequent equations are strictly valid only when the rate of exchange of nitrogen is zero. It is customary to use volumes corrected to standard conditions when working with these equations. In the experimental work involved in this program, both volumes and mass flows are measured and it was found most convenient to analyze the data at the volumes as measured at the mixing chamber pressures and temperatures and to convert mass flow readings to these same conditions. The final values of \dot{V}_{O_2} are then corrected to standard conditions.

Equation (5) for oxygen uptake can be written as:

$$\dot{V}_{O_2} = \dot{V}_{O_2 \text{ in}} - \dot{V}_{O_2} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{\frac{P_{N_2 \text{ out}}}{P_T}}{\frac{P_{N_2 \text{ in}}}{P_T}} \dot{V}_E - \frac{P_{O_2 \text{ out}}}{P_T} \dot{V}_E \quad (7)$$

For convenience, the \dot{V} terms can be replaced by actual volumes determined over a given run time and the oxygen consumption during the run designated as ΔV_{O_2} . Then

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = \frac{V_E}{P_T} P_{O_2 \text{ in}} \times \frac{P_{N_2 \text{ out}}}{P_{N_2 \text{ in}}} - P_{O_2 \text{ out}} \quad (8)$$

Since flow metering is accomplished on the inhalation side the equation may be written

$$V_{CO_2} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{P_{N_2 \text{ in}}}{P_{N_2 \text{ out}}} \quad \text{where no } CO_2 \text{ is present in (9)}$$

the inhaled gas.

Respiratory quotient (R.Q.) may be written as follows:

$$R.Q. = \frac{V_{CO_2}}{V_{O_2}} = \frac{P_{CO_2}}{P_T} \times V_{in} \times \frac{P_{N_2 \text{ in}}}{P_{N_2 \text{ out}}} \times \frac{1}{\Delta V_{O_2}} \quad (10)$$

The volume of oxygen uptake is easily converted to standard conditions (STPD) and to rate of volume uptake for more meaningful information by equation:

$$V_{O_2}(\text{STPD}) = \Delta V_{O_2} \times \frac{60}{\tau} \times \frac{P_{BP}}{760} \times \frac{492}{T_{Lab}} \quad (11)$$

Converting to any other conditions can be done in a similar fashion and will be left to the reader.

The ratio of the partial pressure of the exhaled nitrogen to the inhaled nitrogen $\frac{P_{N_2 \text{ out}}}{P_{N_2 \text{ in}}}$ is computed by knowing the total pressure and the partial pressure of all other constituents. The ratio is hypothetical in that it assumes an isothermal condition from inspiration to expiration. This hypothetical value can be used accurately, however, since temperature and pressure in the exhaled mixing chamber are known and the inhaled volume is computed from a mass flow measurement converted to exhaled mixing chamber temperature and pressure and corrected for the molecular weight of the mixture. The equation becomes:

$$\frac{P_{N_2 \text{ out}}}{P_{N_2 \text{ in}}} = \frac{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O \text{ out}}}{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}} \quad (12)$$

where no CO_2 is present in the inspired gas. The partial pressure of inhaled water vapor is computed from the relative humidity of the inspired air corrected to expired mixing chamber conditions. The partial pressure of the exhaled water vapor is computed for saturation at expired mixing chamber conditions.

Since the term $\frac{P_{N_2 \text{ in}}}{P_{N_2 \text{ out}}}$ represents the ratio of the total inspired to total expired flow under isothermal and isobaric conditions, it is expressed on the data sheets as V_{T_2}/V_{T_1} .

The equations shown above have been used to compute the oxygen uptake from summarized data as shown on the data sheets, figures 14 through 33 . The data sheets contain data from both the analyzer and the laboratory standard, referred to as "bag samples" on the data sheets. The data sheets contain general information as to barometric pressure, temperature, run time, altitude, humidity conditions when required, etc. There are also results of computed values such as density (ρ) and the volumes of gas measured from the "bag sample" (meteorological balloon) called V_{spir} and the volume calculated from an integration of the area trace obtained from the flowmeter, indicated as V_{in} on the data sheet. The columns of data on P_{CO_2} , $P_{\text{O}_2 \text{ in}}$, and $P_{\text{O}_2 \text{ out}}$ are read and averaged from the Offner recorder data traces such as the example shown as figures 34 and 35 . Each recording contains a trace of P_{CO_2} from the analyzer for both exhaled gases in the mixing chamber and from those collected in the balloon. A total pressure and temperature trace are shown. $P_{\text{O}_2 \text{ in}}$ and $P_{\text{O}_2 \text{ out}}$ are shown as well as the mass flow rate for each inspiration. Also shown on each trace is the time record of each run. It may be noted on the flowmetering trace that the beginning of a run is taken in the middle of an inspiration and ended in the middle of an inspiration. This is done so that the total gases collected for that run can be accurately determined from the area under the curve and the exact breaths accounted for on the trace. However, it must be remembered that due to line lengths in the system, possibly two or three breaths entering the balloon were actually breathed prior to the run, thus requiring that fairly stabilized conditions prevail prior to the run. The analyzer was placed in the timer mode during each run sensing inspiratory gases for 30 seconds and expiratory gases for 30 seconds. In order that an average value of P_{CO_2} , $P_{\text{O}_2 \text{ in}}$ and $P_{\text{O}_2 \text{ out}}$ could be used in the calculations, ten points at three different cycle modes were normally selected for averaging.

RESPIRATION ANALYZER

NA-66-389

Run # 20 Date 2-25-66

Figure 14

Subject L.B. Bar 29.91 "Hg 759.7 == Hg
 Work Level Walk O₂ 23.5 mmHg
 Altitude S.L. T = 75 °F
 Supply Gas AIR T_{sp} = 60 °F
 Run Time 83.8 Sec. $\rho_g = .0742 \text{ g/l}^3$
 V_{spir} 22.8 Liters
 $P_{\text{H}_2\text{O}}$ In 9.0 == Hg V_{in} 23.75 Liters
 $P_{\text{H}_2\text{O}}$ Out 22.1 == Hg

ANALYZER

	P_{CO_2}		P_{O_2} in		P_{O_2} out
1	5.20	5.0	156.5	156.5	114.0
2	5.10	5.0			113.5
3	5.05	5.15			113.3
4	5.00	5.10			113.8
5	5.00	5.00			113.9
6	5.20	4.95			114.1
7	5.20	4.90			114.3
8	5.10	5.00			114.5
9	5.10	5.20			115.0
10	5.00	5.20			113.2
50.95	50.50				1139.6
Av 5.10	5.05				114.0
Av 5.08	40.7		156.5		113.6

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2O}}{P_T} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O \text{ out}} - P_{CO_2 \text{ out}}} = \frac{759.7 - 156.5 - 9.0}{759.7 - 113.6 - 22.1 - 40.7} = \frac{594.2}{583.3} = 1.0187$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{\text{in}} = \frac{156.5 \times 23.75}{759.7} = \frac{3716.88}{759.7} = 4.8926$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{in}} \times \frac{V_{T_2}}{V_{T_1}} = \frac{113.6 \times 23.75 \times 1.0187}{759.7} = \frac{2742.79}{759.7} = 3.6104$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 4.8926 - 3.6104 = 1.2822$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{\text{in}} \times \frac{V_{T_2}}{V_{T_1}} \times \frac{1}{\Delta V_{O_2}} = \frac{40.7 \times 23.75 \times 1.0187}{759.7 \times 1.2822} = \frac{9847.01}{974.09} = 1.0109$$

BALLOON

Bag Samples

$$P_{CO_2} = 4.8 \text{ cm} = 38.4 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 114.2 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 156.5 \text{ mm Hg}$$

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2O}}{P_T} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O \text{ out}}} = \frac{759.7 - 114.2 - 38.4 - 22.1}{759.7 - 114.2 - 38.4 - 22.1} = \frac{594.2}{583.3} = 1.0157$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{114.2 \times 22.8}{759.7} = \frac{2603.76}{759.7} = 3.4274$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{\text{spir}}}{V_{T_2}/V_{T_1}} = \frac{156.5 \times 22.8}{759.7 \times 1.0157} = \frac{3568.20}{771.63} = 4.6242$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 4.6242 - 3.4274 = 1.1968$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{1.2822}{1.1968} = 1.0714$$

$$R.Q. \text{ Analyzer} = 1.0109$$

$$\frac{P_{O_2 \text{ out B}} - P_{O_2 \text{ out A}}}{P_{O_2 \text{ in A}} - P_{O_2 \text{ out A}}} = \frac{114.2 - 113.6}{156.5 - 113.6} = \frac{0.6}{42.9} = 0.0140$$

$$\frac{V_A \times V_{T_2}}{V_B \times V_{T_1}} = \frac{23.75}{22.8} \times 1.0187 = 1.060$$

$$V_{O_2 (\text{STPD})} = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_{BP}}{760} \times \frac{492}{T_{\text{lab}}} = 1.2822 \times \frac{60}{83.8} \times \frac{759.7}{760} \times \frac{492}{535} = 0.843 \text{ liters/min}$$

MA-66-389

Run # 21 Date 2-25-66

Figure 15

RESPIRATION ANALYZER

Subject W.A. Bar 29.91 mm Hg 759.7 mm Hg
 Work Level STANDING T = 75 °F
 Altitude S.L. T_{re} = 60 °F
 Supply Gas AIR P_g = .0742 #/ft.³
 Run Time 101.6 Sec. V_{expir} 16.58 Liters
 P_{H₂O} In 9.0 mm Hg V_{in} = 16.52 Liters
 P_{H₂O} Out 22.1 mm Hg

ANALYZER

	P _{O₂}	P _{O₂} in	P _{O₂} out	
1	3.65	3.70	157.3	1 126.2 125.9
2	3.65	3.70	157.3	2 126.2 125.9
3	3.65	3.65	157.3	3 126.2 126.0
4	3.65	3.70	157.3	4 126.2 125.9
5	3.80	3.70	157.3	5 126.2 125.9
6	3.80	3.65	157.3	6 126.1 125.5
7	3.85	3.70	157.3	7 126.0 125.3
8	3.85	3.65	157.3	8 125.0 125.3
9	3.75	3.60	157.3	9 124.7 125.3
10	3.80	3.60	157.3	10 124.3 125.8
	37.45	36.55		1257.10 1254.50 1256.80
Av	3.75	3.69	157.3	Av 125.71 125.45 125.68
Av	3.70 cm	29.6 mm Hg	Av 157.3 mm Hg	Av 125.6 mm Hg

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2O}}{P_T} = \frac{P_T - P_{O_2} \text{ in} - P_{H_2O} \text{ in}}{P_T - P_{O_2} \text{ out} - P_{H_2O} \text{ out}} = \frac{759.7 - 157.3 - 9.0}{759.7 - 125.6 - 22.1} = \frac{593.4}{508.0} = 1.0189$$

$$V_{O_2} \text{ in} = \frac{P_{O_2} \text{ in} \times V_{T_1}}{P_T} = \frac{157.3 \times 16.52}{759.7} = \frac{2598.60}{759.7} = 3.4206$$

$$V_{O_2} \text{ out} = \frac{P_{O_2} \text{ out} \times V_{T_1}}{P_T} = \frac{125.6 \times 16.52}{759.7} = \frac{2074.13}{759.7} = 2.7288$$

$$\Delta V_{O_2} = V_{O_2} \text{ in} - V_{O_2} \text{ out} = 3.4206 - 2.7288 = .6918$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2} \text{ out} \times V_{T_1} \times \frac{1}{P_T}}{P_{O_2} \text{ in} \times V_{T_1} \times \frac{1}{P_T}} = \frac{29.6 \times 16.52 \times 1.0189 \times 1}{759.7 \times .6918} = \frac{498.23}{484.54} = 1.0283$$

BALLOON

Bag Samples

$$P_{CO_2} = 3.30 \text{ cm} = 26.4 \text{ mm Hg}$$

$$P_{O_2} \text{ out} = 128.2 \text{ mm Hg}$$

$$P_{O_2} \text{ in} = 157.3 \text{ mm Hg}$$

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2O}}{P_T} = \frac{P_T - P_{O_2} \text{ in} - P_{H_2O} \text{ in}}{P_T - P_{O_2} \text{ out} - P_{H_2O} \text{ out}} = \frac{759.7 - 128.2 - 593.4}{759.7 - 128.2 - 26.4} = \frac{53.3}{505.1} = 1.0178$$

$$V_{O_2} \text{ out} = \frac{P_{O_2} \text{ out} \times V_{T_1}}{P_T} = \frac{128.2 \times 16.52}{759.7} = \frac{2125.56}{759.7} = 2.7880$$

$$V_{O_2} \text{ in} = \frac{P_{O_2} \text{ in} \times V_{T_1}}{P_T} = \frac{157.3 \times 16.52}{759.7 \times 1.0178} = \frac{2608.03}{773.22} = 3.3729$$

$$\Delta V_{O_2} = V_{O_2} \text{ in} - V_{O_2} \text{ out} = 3.3729 - 2.7880 = .5849$$

SUMMARY

$$\frac{\Delta V_{O_2} \text{ Analyzer}}{\Delta V_{O_2} \text{ Spirometer}} = \frac{.6378}{.5749} = 1.1180$$

$$R.Q. \text{ Analyzer} = 1.0283$$

$$\frac{P_{O_2} \text{ outB} - P_{O_2} \text{ outA}}{P_{O_2} \text{ inA} - P_{O_2} \text{ outA}} = \frac{128.2 - 125.6}{157.3 - 125.6} = \frac{2.6}{31.7} = .082$$

$$\frac{V_{\text{anal}} \times V_{T_1}}{V_{\text{expir}} \times V_{T_1}} = \frac{16.52 \times 1.0189}{16.58} = 1.016$$

$$V_{O_2} (\text{STPD}) = \Delta V_{O_2} \times \frac{P_{BP}}{P_T} \times \frac{492}{760} = .6378 \times \frac{60}{101.6} \times \frac{759.7}{760} \times \frac{492}{555} = 0.346 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

Run # 22 Date 2-25-66

Figure 16

Subject W.A. Bar 29.91 mm Hg 759.714 mm Hg
 Work Level WALKING 0% T = 75 °F
 Altitude S.L. T_{re} = 60 °F
 Supply Gas AIR ρ_g = .0742 g/l
 Run Time 87.8 Sec. V_{spir} 22.9 Liters
 P_{H₂O} In 9.0 mm Hg V_{in} = 23.2 Liters
 P_{H₂O} Out 22.1 mm Hg

ANALYZER

P_{CO_2}			$P_{O_2 \text{ in}}$			$P_{O_2 \text{ out}}$					
1	<u>4.35</u>	<u>4.05</u>	<u>4.25</u>	1	<u>157.0</u>	<u>157.3</u>	<u>156.7</u>	1	<u>115.8</u>	<u>118.2</u>	<u>115.8</u>
2	<u>4.35</u>	<u>4.15</u>	<u>4.40</u>	2	<u>157.0</u>	<u>157.3</u>	<u>156.7</u>	2	<u>115.8</u>	<u>118.0</u>	<u>114.7</u>
3	<u>4.30</u>	<u>4.20</u>	<u>4.40</u>	3	<u>157.0</u>	<u>157.3</u>	<u>156.7</u>	3	<u>115.9</u>	<u>117.7</u>	<u>119.2</u>
4	<u>4.30</u>	<u>4.25</u>	<u>4.30</u>	4	<u>157.0</u>	<u>157.3</u>	<u>156.7</u>	4	<u>116.0</u>	<u>117.3</u>	<u>114.3</u>
5	<u>4.40</u>	<u>4.25</u>	<u>4.30</u>	5	<u>157.0</u>	<u>157.2</u>	<u>156.7</u>	5	<u>116.0</u>	<u>117.0</u>	<u>114.5</u>
6	<u>4.50</u>	<u>4.30</u>	<u>4.40</u>	6	<u>157.0</u>	<u>157.0</u>	<u>156.9</u>	6	<u>116.0</u>	<u>117.0</u>	<u>115.2</u>
7	<u>4.45</u>	<u>4.40</u>	<u>4.25</u>	7	<u>156.8</u>	<u>157.0</u>	<u>156.9</u>	7	<u>115.8</u>	<u>117.0</u>	<u>115.8</u>
8	<u>4.30</u>	<u>4.40</u>	<u>4.20</u>	8	<u>156.7</u>	<u>157.0</u>	<u>157.0</u>	8	<u>115.2</u>	<u>116.3</u>	<u>116.0</u>
9	<u>4.15</u>	<u>4.35</u>	<u>4.20</u>	9	<u>156.5</u>	<u>157.0</u>	<u>157.0</u>	9	<u>114.2</u>	<u>116.2</u>	<u>115.5</u>
10	<u>4.05</u>	<u>4.20</u>	<u>4.35</u>	10	<u>156.5</u>	<u>157.0</u>	<u>157.0</u>	10	<u>114.0</u>	<u>116.0</u>	<u>115.0</u>
	<u>43.15</u>	<u>42.55</u>	<u>43.05</u>		<u>1568.5</u>	<u>1571.4</u>	<u>1568.3</u>		<u>1154.7</u>	<u>1170.7</u>	<u>1151.0</u>
Av	<u>4.32</u>	<u>4.26</u>	<u>4.31</u>	Av	<u>156.85</u>	<u>157.14</u>	<u>156.83</u>	Av	<u>115.47</u>	<u>117.07</u>	<u>115.10</u>
Av	<u>4.30</u>	cm	<u>34.4</u>	mm Hg	Av	<u>156.94</u>	mm Hg	Av	<u>115.88</u>	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{759.71 - 156.94 - 9.0}{759.71 - 115.88 - 22.1 - 34.4} = \frac{593.77}{587.33} = 1.0110$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}}}{P_T} \times V_{in} = \frac{156.94 \times 23.2}{759.71} = \frac{3641}{759.71} = 4.7926$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{115.88 \times 23.2 \times 1.0110}{759.71} = \frac{2717.99}{759.71} = 3.5777$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 4.7926 - 3.5777 = 1.2149$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{34.4 \times 23.2 \times 1.011 \times 1}{759.7 \times 1.2149} = \frac{806.86}{922.97} = .8741$$

BALLOON

Bag Samples

$$P_{CO2} = 4.2 \text{ cm} = 33.5 \text{ mm Hg}$$

$$P_{O2 \text{ out}} = 116.2 \text{ mm Hg}$$

$$P_{O2 \text{ in}} = 156.94 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{593.77}{759.7 - 116.2 - 33.5 - 22.1} = \frac{593.77}{587.91} = 1.010$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{spir} = \frac{116.2 \times 22.9}{759.71} = \frac{2660.98}{759.71} = 3.5026$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{156.94 \times 22.9}{759.71 \times 1.010} = \frac{3593.93}{759.71} = 4.6838$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 4.6838 - 3.5026 = 1.1812$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{1.2149}{1.1812} = 1.0285$$

$$R.Q. \text{ Analyzer} = .8741$$

$$\frac{P_{O2 \text{ out}} - P_{O2 \text{ outA}}}{P_{O2 \text{ in}} - P_{O2 \text{ outA}}} = \frac{116.2 - 115.88}{156.94 - 115.88} = \frac{0.32}{41.06} = 0.0078$$

$$\frac{V_{anal}}{V_{spir}} \times \frac{V_{T2}}{V_{T1}} = \frac{23.2}{22.9} \times 1.011 = 1.022$$

$$V_{O2 \text{ (STPD)}} = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_{BP}}{760} \times \frac{492}{T_{lab}} = 1.2199 \times \frac{60}{87.8} \times \frac{759.71}{760} \times \frac{492}{535} = 0.763 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 23 Date 2-25-66

Figure 17

Subject L.B. Bar 29.91 "Hg 759.7 "Hg
 Work Level STANDING T = 75 °F
 Altitude S.L. Tve = 60 °F
 Supply Gas AIR $\rho_g = .0742$ #/ft³
 Run Time 106.6 Sec. $V_{\text{spir}} = 16.5$ Liters
 P_{H_2O} in 9.0 "Hg $V_{\text{in}} = 15.53$ Liters
 P_{H_2O} Out 22.1 "Hg

ANALYZER

	P_{CO_2}		P_{O_2} in		P_{O_2} out
1	3.80	4.15	4.05	1 156.5	156.5 156.5
2	3.80	4.00	3.90	2	126.2 121.5 123.1
3	3.75	3.70	3.80	3	126.2 122.2 123.8
4	3.80	3.70	3.80	4	126.2 123.1 124.2
5	3.90	3.80	3.80	5	126.1 123.9 124.7
6	3.85	3.90	3.75	6	126.1 123.9 125.2
7	3.75	3.90	3.75	7	126.0 123.8 125.2
8	3.65	3.80	3.68	8	125.7 123.5 125.2
9	3.65	3.80	3.65	9	125.2 122.7 125.5
10	3.85	3.90	3.68	10	125.3 122.2 125.8
	37.80	38.65	37.86		1259.3 1227.3 1245.2
Av	3.78	3.87	3.79	Av	125.9 122.7 124.5
Av	3.81	cm	30.5	Av	156.5 "Hg
				Av	124.4 "Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{759.7 - 156.5 - 9.0}{759.7 - 124.4 - 22.1 - 30.5} = \frac{594.2}{582.7} = 1.020$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{\text{in}}}{P_T} = \frac{156.5 \times 15.53}{759.7} = \frac{2430.44}{759.7} = 3.1990$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{\text{in}} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{124.4 \times 15.53 \times 1.020}{759.7} = \frac{1970.56}{759.7} = 2.5939$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 3.1990 - 2.5939 = .6051$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{\text{in}} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{30.5 \times 15.53 \times 1.020}{759.7 \times .6051} = \frac{483.13}{459.62} = 1.0512$$

BALLOON

Bag Samples

$$P_{CO_2} = 3.7 \text{ cm} = 29.6 \text{ "Hg}$$

$$P_{O_2 \text{ out}} = 124.5 \text{ "Hg}$$

$$P_{O_2 \text{ in}} = 156.5 \text{ "Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{759.7 - 156.5 - 29.5 - 22.1}{759.7 - 124.5 - 29.5 - 22.1} = \frac{594.2}{583.5} = 1.0183$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{124.5 \times 16.5}{759.7} = 2.7040$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{\text{spir}}}{V_{T2}/V_{T1}} = \frac{156.5 \times 16.5}{759.7 \times 1.0183} = \frac{2582.25}{773.60} = 3.3380$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 3.3380 - 2.7040 = .6340$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{.6051}{.6340} = .9544$$

$$R.Q. \text{ Analyzer} = 1.0512$$

$$\frac{P_{O_2 \text{ outB}} - P_{O_2 \text{ outA}}}{P_{O_2 \text{ inA}} - P_{O_2 \text{ outA}}} = \frac{124.5 - 124.4}{156.5 - 124.4} = \frac{0.1}{32.1} = .00312$$

$$\frac{V_{\text{anal}}}{V_{\text{bag}}} \times \frac{V_{T2}}{V_{T1}} = \frac{15.53}{16.50} \times 1.02 = .960$$

$$V_{O_2 (\text{STPD})} = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_{BP}}{P_{\text{lab}}} \times \frac{492}{T_{\text{lab}}} = .6051 \times \frac{60}{106.6} \times \frac{759.7}{760} \times \frac{492}{533} = 0.313 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

Run # 24 Date 3-2-66

Figure 18

Subject L.B. Bar 29.88 "Hg 758.95 "Hg
 Work Level STANDING T = 69 °F
 Altitude S.L. T_{wo} = 52 °F
 Supply Gas 41.1% - 58.9% N₂ P = .0767 #/in³
 Run Time 146.4 Sec. V_{spir} 16.78 Liters
 P_{H₂O} In DRY "Hg V_{in} = 15.80 Liters
 P_{H₂O} Out "Hg

ANALYZER

	P _{CO₂}			P _{O₂} in			P _{O₂} out		
1	3.40	3.60	4.00	311.0	311.0	311.0	266.0	271.0	270.0
2	3.45	3.65	4.00				266.0	271.0	270.0
3	3.55	3.65	4.05				266.0	271.0	270.0
4	3.55	3.65	4.10				266.0	271.0	270.0
5	3.55	3.70	4.05				266.0	271.0	270.0
6	3.55	3.70	3.95				266.0	270.0	270.0
7	3.60	3.70	3.70				266.0	270.0	270.0
8	3.60	3.70	3.60				266.0	270.0	270.0
9	3.60	3.60	3.60				267.0	270.0	270.0
10	3.55	3.60	3.60				268.0	270.0	270.0
	35.40	36.55	38.65				2663.0	2705.0	2700.0
Av	3.54	3.66	3.87	Av	311.0	311.0	Av	266.3	270.5
Av	3.69			Av	311.0		Av	268.9	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{758.95 - 311.0 - 0}{758.95 - 268.9 - 18.1 - 29.3} = \frac{447.95}{442.65} = 1.0120$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}}}{P_T} \times V_{in} = \frac{311.0 \times 15.80}{758.95} = \frac{4913.8}{758.95} = 6.4745$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{268.9 \times 15.80 \times 1.012}{758.95} = \frac{4299.6}{758.95} = 5.6652$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 6.4745 - 5.6652 = .8093$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{29.3 \times 15.80 \times 1.012 \times 1}{758.95 \times .8093} = \frac{468.50}{613.99} = .763$$

BALLOON

Bag Samples

$$P_{CO2} = 3.3 \text{ cm} = 26.4 \text{ "Hg}$$

$$P_{O2 \text{ out}} = 267.0 \text{ "Hg}$$

$$P_{O2 \text{ in}} = 311.0 \text{ "Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{447.95}{758.95 - 267.0 - 26.4 - 18.1} = \frac{447.95}{447.45} = 1.0011$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{spir} = \frac{267.0 \times 16.78}{758.95 \times 1.0011} = 5.9032$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{311.0 \times 16.78}{758.95 \times 1.0011} = \frac{5218.58}{759.78} = 6.8685$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 6.8685 - 5.9032 = .9653$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{.8093}{.9653} = .8380$$

$$R.Q. \text{ Analyzer} = .763$$

$$\frac{P_{O2 \text{ out}_B} - P_{O2 \text{ out}_A}}{P_{O2 \text{ in}_A} - P_{O2 \text{ out}_A}} = \frac{267 - 268.9}{311 - 268.9} = \frac{-1.9}{42.1} = -0.0452$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{15.8}{16.78} \times 1.012 = .953$$

$$V_{O2(\text{STPD})} = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_{SP}}{760} \times \frac{492}{T_{\text{Lab}}} = .8093 \times \frac{60}{146.4} \times \frac{758.95}{760} \times \frac{492}{529} = 0.308 \text{ liters/min.}$$

RESPIRATION ANALYZER

 HA-66-389
 Run # 25 Date 3-4-66

Figure 19

Subject L.B. Bar 30.19 mm Hg 766.826 mm Hg
 Work Level Standing T = 76 °F
 Altitude 10,000 ft Tve = -- °F
 Supply Gas Demand Regulator P_S = .0511 #/ft³
 Run Time 131.4 Sec. V_{spir} 17.22 Liters
 P_{H₂O} In 0 mm Hg V_{in} = 17.10 Liters
 P_{H₂O} Out 23.0 mm Hg P_T = 517 mm Hg

ANALYZER

	P _{CO₂}			P _{O₂} in			P _{O₂} out		
1	3.35	3.50	3.45	197.0	198.0	198.0	161.0	162.5	162.0
2	3.30	3.50	3.40	197.0	198.0	198.0	161.0	162.5	162.0
3	3.30	3.55	3.40	197.0	197.5	197.5	161.0	162.5	162.0
4	3.35	3.50	3.40	197.5	197.5	197.5	161.0	162.5	162.0
5	3.30	3.50	3.35	197.5	197.5	197.5	161.0	162.5	162.0
6	3.30	3.45	3.35	197.5	197.0	197.0	161.0	162.5	162.0
7	3.30	3.45	3.35	197.5	197.5	197.5	161.0	162.5	162.0
8	3.35	3.45	3.40	198.0	197.0	197.0	162.0	162.5	162.0
9	3.35	3.40	3.25	199.0	197.0	197.0	162.0	162.5	162.0
10	3.25	3.40	3.25	199.0	197.0	197.0	162.0	162.5	163.0
Av	3.315	3.47	3.36	Av 197.7	197.4	197.4	Av 161.3	162.5	162.1
Av	3.393	cm 27.1	mm Hg	Av 197.55	mm Hg	mm Hg	Av 162.0	mm Hg	mm Hg

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2}}{P_{H_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{517 - 197.55 - 0}{517 - 162.0 - 23.0 - 27.1} = \frac{319.45}{304.90} = 1.0477$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{in}}{P_T} = \frac{197.55 \times 17.10}{517} = \frac{3378.11}{517} = 6.5341$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{in} \times \frac{V_{T_2}}{V_{T_1}}}{P_T} = \frac{162.0 \times 17.10 \times 1.0477}{517} = \frac{2902.34}{517} = 5.6138$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.5341 - 5.6138 = .9203$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T_2}}{V_{T_1}} \times \frac{1}{\Delta V_{O_2}} = \frac{27.1 \times 17.10 \times 1}{517 \times .9203} = \frac{4634.10}{4757.95} = .974$$

BALLOON

Bag Samples

$$P_{CO_2} = 3.15 \text{ cm} = 25.3 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 163.0 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 197.55 \text{ mm Hg}$$

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{H_2}}{P_{H_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{517 - 163.0 - 25.3 - 23}{517 - 163.0 - 3.15 - 23} = \frac{319.45}{305.70} = 1.0450$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{163 \times 17.22}{517} = \frac{2806.86}{517} = 5.4291$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2}}{P_T} \times \frac{V_{\text{spir}}}{\frac{V_{T_2}}{V_{T_1}}} = \frac{197.55 \times 17.22}{517 \times 1.0450} = \frac{3401.81}{540.27} = 6.2965$$

$$\Delta V_{CO_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.2965 - 5.4291 = .8674$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{.9203}{.8674} = 1.0610$$

$$R.Q. \text{ Analyzer} = .974$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{163 - 162}{197.55 - 162} = \frac{1}{35.55} = .0281$$

$$\frac{V_A}{V_B} \times \frac{V_{T_2}}{V_{T_1}} = \frac{17.10}{17.22} \times 1.0477 = 1.040$$

$$V_{O_2 (\text{STPD})} = \Delta V_{O_2} \times \frac{60}{2} \times \frac{P_T}{P_{\text{lab}}} \times \frac{492}{536} = .9203 \times \frac{60}{131.4} \times \frac{517}{760} \times \frac{492}{536} = 0.263 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 26 Date 1-4-66

Figure 20

Subject L.B. Bar 30.19 mm Hg 766.826 mm Hg
 Work Level Walk O₂ at 3.5 mph
 Altitude 10,000 ft T = 76 °F
 Supply Gas Diluter Demand P_g = .0511 #/ft³
 Run Time 123.5 Sec. V_{spir} 29.72 Liters
 P_{H2O} In Zero mm Hg V_{in} = 31.2 Liters
 P_{H2O} Out 23.0 mm Hg P_T = 517 mm Hg

ANALYZER

	P _{CO2}				P _{O2} in				P _{O2} out		
1	4.62	4.60	4.40	1	2.82	2.83	2.87	1	1.81	1.82	1.82
2	4.65	4.55	4.35	2	2.81	2.83	2.86	2	1.81	1.81	1.82
3	4.70	4.60	4.35	3	2.81	2.84	2.84	3	1.81	1.81	1.83
4	4.70	4.60	4.40	4	2.81	2.83	2.82	4	1.81	1.81	1.82
5	4.70	4.60	4.45	5	2.81	2.83	2.81	5	1.80	1.80	1.82
6	4.65	4.55	4.45	6	2.81	2.82	2.81	6	1.80	1.80	1.82
7	4.65	4.50	4.35	7	2.81	2.82	2.80	7	1.79	1.79	1.80
8	4.65	4.45	4.30	8	2.81	2.82	2.80	8	1.79	1.79	1.80
9	4.65	4.50	4.25	9	2.81	2.82	2.80	9	1.79	1.79	1.79
10	4.65	4.50	4.25	10	2.82	2.82	2.80	10	1.80	1.80	1.80
Av	5.13	4.55	4.36	Av	2.81	2.83	2.82	Av	1.81	1.80	1.81
Av	4.68	cm	37.2	mm Hg	Av	191.8	mm Hg	Av	141.4	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{517 - 191.8 - 0}{517 - 141.4 - 23.0 - 37.2} = \frac{325.2}{315.4} = 1.0311$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}} \times V_{in}}{P_T} = \frac{191.8 \times 31.2}{517} = \frac{5984.16}{517} = 11.5748$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{141.4 \times 31.2 \times 1.0311}{517} = \frac{4548.88}{517} = 8.7986$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 11.5748 - 8.7986 = 2.7762$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{37.2 \times 31.2 \times 1.0311 \times 1}{517 \times 2.7762} = \frac{1196.74}{1435.30} = .834$$

BALLOON

Bag Samples

$$P_{CO2} = \frac{4.63}{cm} = \frac{36.8}{mm Hg}$$

$$P_{O2 \text{ out}} = \frac{141.0}{mm Hg}$$

$$P_{O2 \text{ in}} = \frac{191.8}{mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{517 - 191.8 - 23}{517 - 141 - 36.8 - 23} = \frac{325.2}{315.2} = 1.0285$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{spir} = \frac{141 \times 29.72}{517} = \frac{4190.28}{517} = 8.1055$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{191.8 \times 29.72}{517 \times 1.0285} = \frac{5700.30}{531.18} = 10.7316$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 10.7316 - 8.1055 = 2.6261$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{2.7762}{2.6261} = 1.0572$$

$$R.Q. \text{ Analyzer} = .834$$

$$\frac{P_{O2 \text{ outB}} - P_{O2 \text{ outA}}}{P_{O2 \text{ inA}} - P_{O2 \text{ outA}}} = \frac{141.0 - 141.4}{191.8 - 141.8} = \frac{-0.4}{50} = -0.008$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{31.2}{29.72} \times 1.0311 = 1.084$$

$$\dot{V}_{O2} (\text{STPD}) = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_T}{760} \times \frac{492}{T_{\text{Lab}}} = 2.7762 \times \frac{60}{123.5} \times \frac{517}{760} \times \frac{492}{536} = 0.84 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

3-7-66

Run # 27 Date

Figure 21

Subject L. B. Bar 29.945 "Hg 760.603 = Hg
 Work Level Standing T = 81 °F
 Altitude 15,000 ft T_{we} = _____ °F
 Supply Gas Diluter-Demand Reg. ρ_g = .0398 #/ft³
 Run Time 135 Sec. V_{spir} 21.66 Liters
 P_{H₂O} In Zero = Hg V_{in} = 20.0 Liters
 P_{H₂O} Out 26.9 = Hg P_T = 426 = Hg

ANALYZER

	P _{CO₂}		P _{O₂} in		P _{O₂} out
1	<u>3.18</u> <u>3.30</u>		1 <u>160.3</u> <u>165.5</u>		1 <u>128.2</u> <u>128.1</u>
2	<u>3.20</u> <u>3.32</u>		2 <u>160.1</u> <u>165.5</u>		2 <u>128.2</u> <u>128.2</u>
3	<u>3.22</u> <u>3.33</u>		3 <u>160.0</u> <u>164.0</u>		3 <u>128.2</u> <u>128.2</u>
4	<u>3.25</u> <u>3.25</u>		4 <u>160.0</u> <u>164.2</u>		4 <u>128.2</u> <u>128.2</u>
5	<u>3.25</u> <u>3.20</u>		5 <u>160.0</u> <u>164.2</u>		5 <u>128.0</u> <u>128.2</u>
6	<u>3.33</u> <u>3.25</u>		6 <u>159.9</u> <u>164.2</u>		6 <u>127.9</u> <u>128.2</u>
7	<u>3.40</u> <u>3.25</u>		7 <u>159.9</u> <u>164.1</u>		7 <u>127.9</u> <u>128.1</u>
8	<u>3.40</u> <u>3.25</u>		8 <u>159.9</u> <u>164.1</u>		8 <u>127.7</u> <u>128.1</u>
9	<u>3.35</u> <u>3.25</u>		9 <u>160.0</u> <u>164.1</u>		9 <u>127.7</u> <u>128.0</u>
10	<u>3.28</u> <u>3.25</u>		10 <u>160.2</u> <u>164.2</u>		10 <u>127.7</u> <u>128.0</u>
Av	<u>3.29</u> <u>3.27</u>		Av <u>160.0</u> <u>164.4</u>		Av <u>128.0</u> <u>128.1</u>
Av	<u>3.28</u> cm = <u>26.2</u> = Hg		Av <u>162.2</u> = Hg		Av <u>128.1</u> = Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H_2O}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426 - 162.2}{426 - 128.1 - 26.9 - 26.2} = \frac{263.8}{244.8} = 1.078$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{in} = \frac{162.2}{426} \times 20.0 = 7.615$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{128.1}{426} \times 20.0 \times 1.078 = 6.483$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 7.615 - 6.483 = 1.132$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{26.2}{426} \times 20 \times \frac{1.078}{1.132} = 1.170$$

BALLOON

Bag Samples

$$P_{CO_2} = \underline{3.22} \text{ cm} = \underline{25.7} = \text{Hg}$$

$$P_{O_2 \text{ out}} = \underline{131.8} = \text{Hg}$$

$$P_{O_2 \text{ in}} = \underline{128.1} = \text{Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H_2O}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426 - 162.2}{426 - 131.8 - 25.7 - 26.9} = \frac{263.8}{241.6} = 1.092$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{131.8}{426} \times 21.26 = 6.578$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{\text{spir}}}{V_{T2}/V_{T1}} = \frac{162.2}{426} \times \frac{21.26}{1.092} = 7.413$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 7.413 - 6.578 = .835$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{1.132}{.835} = 1.360$$

$$R.Q. \text{ Analyzer} = 1.170$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{131.8 - 128.1}{162.2 - 128.1} = \frac{3.7}{34.1} = 0.1085$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{20}{21.26} \times 1.078 = 1.015$$

$$V_{O_2 (\text{STPD})} = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_T}{P_{\text{lab}}} = 1.132 \times \frac{60}{135} \times \frac{426}{760} = \frac{426}{760} \times \frac{422}{541} = 0.252 \text{ liters/min.}$$

RESPIRATION ANALYZER

NA-66-389

Run # 28 Date 3-7-66

Figure 22

Subject L.B. Bar 29.945 "Hg 760.603 mm Hg
 Work Level WALK 0% @ 3.5 mph T = 81 °F
 Altitude 15,000 Ft. T_{re} = - °F
 Supply Gas DILUTER-DEMAND REG. P_s .0398 #/ft³
 Run Time 148.35 Sec. V_{spir} 37.58 Liters
 P_{H₂O} In 0 mm Hg V_{in} = 40.6 Liters
 P_{H₂O} Out 26.9 mm Hg P_T 426.0 mm Hg

ANALYZER

	P _{CO₂}		P _{O₂ in}		P _{O₂ out}
1	4.62	4.50	1	160.0	163.3
2	4.63	4.50	2	160.0	163.3
3	4.61	4.48	3	160.0	163.0
4	4.62	4.42	4	160.2	162.5
5	4.65	4.37	5	160.5	162.0
6	4.65	4.40	6	160.8	162.0
7	4.69	4.30	7	160.8	162.0
8	4.62	4.28	8	161.0	162.2
9	4.62	4.18	9	160.8	162.1
10	4.63	4.20	10	160.7	162.2
Av	4.63	4.63	Av	160.5	162.5
Av	4.50	36.0 mm Hg	Av	161.5	mm Hg
			Av	110.3	mm Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H_2O}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426.0 - 161.5 - 0}{426.0 - 110.3 - 26.9 - 36} = \frac{264.5}{252.8} = 1.0463$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{in}}{P_T} = \frac{161.5 \times 40.6}{426} = \frac{6556.9}{426} = 15.3918$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{110.3 \times 40.6 \times 1.0463}{426} = \frac{4694.94}{426} = 11.0210$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 15.3918 - 11.0210 = 4.3708$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{36.0 \times 40.6 \times 1.0463 \times 0}{426 \times 4.3708} = \frac{1529.27}{1861.96} = .821$$

BALLOON

Bag Samples

$$P_{CO_2} = 4.365 \text{ cm} = 34.8 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 108.91 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 161.5 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H_2O}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426.0 - 161.5 - 0}{426.0 - 108.91 - 34.8 - 26.9} = \frac{264.5}{255.79} = 1.0341$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{spir} = \frac{108.91 \times 37.58}{426} = \frac{4077.81}{426} = 9.5723$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{161.5 \times 37.58}{426 \times 1.0341} = \frac{6069.17}{440.53} = 13.777$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 13.777 - 9.5723 = 4.2047$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{4.3708}{4.2047} = 1.0395$$

$$R.Q. \text{ Analyzer} = .821$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{108.91 - 110.3}{161.5 - 110.3} = \frac{-1.8}{51.2} = -0.0352$$

$$\frac{V_A}{V_B} = \frac{V_{T2}}{V_{T1}} = \frac{40.6}{37.58} \times 1.0463 = 1.132$$

$$V_{O_2 (\text{STPD})} = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_T}{P_{\text{lab}}} = 4.3708 \times \frac{60}{100} \times \frac{760}{426} = 0.90 \text{ liters/min}$$

RESPIRATION ANALYZER

BA-66-389

Run # 29 Date 3-8-66

Figure 23

Subject L. B. Bar 30.14 mm Hg 765.556 mm Hg
 Work Level Standing T = 79 °F
 Altitude 5000 ft T_{ve} = 79 °F
 Supply Gas Diluter-Demand Reg. P_s = .0617 #/ft³
 Run Time 149.0 Sec. V_{spir} 26.20 Liters
 P_{H2O} In ----- mm Hg V_{in} = 25.60 Liters
 P_{H2O} Out 25.3 mm Hg P_T = 628.7 mm Hg

ANALYZER

P _{CO2}				P _{O2} in				P _{O2} out			
1	<u>3.28</u>	<u>3.35</u>	<u>320</u>	1	<u>114.3</u>	<u>114.3</u>		1	<u>82.0</u>	<u>80.7</u>	<u>83.0</u>
2	<u>3.25</u>	<u>3.35</u>	<u>3.17</u>	2	<u>114.3</u>	<u>114.3</u>		2	<u>82.0</u>	<u>81.0</u>	<u>83.0</u>
3	<u>3.27</u>	<u>3.30</u>	<u>3.17</u>	3	<u>114.3</u>	<u>114.3</u>		3	<u>82.1</u>	<u>81.2</u>	<u>83.0</u>
4	<u>3.28</u>	<u>3.30</u>	<u>3.15</u>	4	<u>114.6</u>	<u>114.2</u>		4	<u>82.1</u>	<u>81.5</u>	<u>83.0</u>
5	<u>3.25</u>	<u>3.28</u>	<u>3.13</u>	5	<u>114.6</u>	<u>114.0</u>		5	<u>82.1</u>	<u>81.5</u>	<u>83.0</u>
6	<u>3.27</u>	<u>3.25</u>	<u>3.12</u>	6	<u>114.5</u>	<u>114.0</u>		6	<u>82.1</u>	<u>81.7</u>	<u>83.2</u>
7	<u>3.29</u>	<u>3.20</u>	<u>3.10</u>	7	<u>115.0</u>	<u>114.1</u>		7	<u>82.1</u>	<u>81.7</u>	<u>83.5</u>
8	<u>3.25</u>	<u>3.20</u>	<u>3.08</u>	8	<u>115.3</u>	<u>114.2</u>		8	<u>82.1</u>	<u>81.8</u>	<u>83.5</u>
9	<u>3.27</u>	<u>3.17</u>	<u>3.5</u>	9	<u>115.5</u>	<u>114.1</u>		9	<u>82.1</u>	<u>81.9</u>	<u>83.5</u>
10	<u>3.25</u>	<u>3.12</u>	<u>3.03</u>	10	<u>115.5</u>	<u>114.0</u>		10	<u>82.1</u>	<u>82.0</u>	<u>83.5</u>
Av	<u>3.27</u>	<u>3.25</u>	<u>3.12</u>	Av	<u>114.8</u>	<u>114.2</u>		Av	<u>82.1</u>	<u>81.5</u>	<u>83.2</u>
					<u>114.5</u>				<u>82.4</u>		
Av	<u>3.21</u>	<u>cm 25.7</u>	<u>mm Hg</u>	Av	<u>230.0</u>	<u>mm Hg</u>		Av	<u>197.8</u>	<u>mm Hg</u>	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{628.7 - 230 - 0}{628.7 - 197.8 - 25.3 - 25.7} = \frac{398.7}{379.9} = 1.0495$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}} \times V_{in}}{P_T} = \frac{230 \times 25.60}{628.7} = \frac{5888}{628.7} = 9.3654$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{197.8 \times 25.60 \times 1.0495}{628.7} = \frac{5314.33}{628.7} = 8.4529$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 9.3654 - 8.4529 = .9125$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{25.7 \times 25.60 \times 1.0495 \times 1}{628.7 \times .9125} = \frac{690.49}{573.69} = 1.2036$$

BALLOON

Bag Samples

$$P_{CO2} = 3.12 \text{ cm} = 25.0 \text{ mm Hg}$$

$$P_{O2 \text{ out}} = 197.0 \text{ mm Hg}$$

$$P_{O2 \text{ in}} = 230.0 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{628.7 - 197 - 25 - 25.3}{628.7 - 197 - 25 - 25.3} = \frac{398.7}{398.7} = 1.0494$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{197 \times 26.20}{628.7} = \frac{5161.40}{628.7} = 8.2096$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{\text{spir}}}{V_{T2}/V_{T1}} = \frac{230 \times 26.20}{628.7 \times 1.0494} = \frac{6026}{657.24} = 9.1686$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 9.1686 - 8.2096 = .9590$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{.9125}{.9590} = .9515$$

$$R.Q. \text{ Analyzer} = 1.2036$$

$$\frac{P_{O2 \text{ out}_B} - P_{O2 \text{ out}_A}}{P_{O2 \text{ in}_A} - P_{O2 \text{ out}_A}} = \frac{197 - 197.8}{230 - 197.8} = \frac{.8}{32.2} = .0249$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{25.6}{26.2} \times 1.0495 = 1.025$$

$$\dot{V}_{O2(\text{STPD})} = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_T}{760} \times \frac{492}{T_{\text{lab}}} = .9125 \times \frac{60}{140} \times \frac{628.7}{760} \times \frac{492}{539} = 0.295 \text{ liters/min.}$$

RESPIRATION ANALYZER

 RA-66-389
 Run # 30 Date 3-8-66

Figure 24

Subject L. B. Bar 30.14 "Hg 765.556 mm Hg
 Work Level Walk % at 3.5 mph T = 79 °F
 Altitude 5000 ft Tve = °F
 Supply Gas Diluter-Demand Ref. P_S = .0617 #/ft³
 Run Time 160.1 Sec. V_{spir} 52.68 Liters
 P_{H₂O} In Dry mm Hg V_{in} = 52.2 Liters
 P_{H₂O} Out 25.3 mm Hg P_T = 628.7 mm Hg

ANALYZER

	P _{CO₂}		P _{O₂} in		P _{O₂} out
1	5.3	5.45	106.2	108.3	110.3
2	5.32	5.40	106.0	108.5	110.3
3	5.32	5.50	105.8	108.7	110.3
4	5.30	5.50	105.9	109.2	110.5
5	5.30	5.52	106.0	109.0	111.2
6	5.28	5.58	106.3	108.5	111.2
7	5.28	5.50	106.3	108.3	111.3
8	5.25	5.55	106.3	108.1	111.5
9	5.25	5.55	106.3	108.0	111.7
10	5.18	5.48	106.3	108.2	111.7
Av	5.28	5.50	106.1	108.5	111.0
Av	5.39	cm 43.1 mm Hg	224.0	mm Hg	174.0 mm Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O \text{ out}}} = \frac{628.7 - 224 - 0}{628.7 - 174 - 25.3 - 43.1} = \frac{404.7}{386.3} = 1.0476$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{in}}{P_T} = \frac{224 \times 52.2}{628.7} = \frac{11692.80}{628.7} = 18.5984$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{174 \times 52.2 \times 1.0476}{628.7} = \frac{9515.14}{628.7} = 15.1346$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 18.5984 - 15.1346 = 3.4638$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{43.1 \times 52.2 \times 1.0476 \times 1}{628.7 \times 3.4638} = \frac{2356.91}{2177.69} = 1.0823$$

BALLOON

Bag Samples

$$P_{CO_2} = 5.35 \text{ cm} = 42.8 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 175.2 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 224.0 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{628.7 - 175.2 - 42.8 - 25.3}{628.7 - 175.2 - 42.8 - 25.3} = \frac{404.7}{385.4} = 1.0501$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{spir} = \frac{175.2 \times 52.68}{628.7} = \frac{9229.54}{628.7} = 14.6804$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{224 \times 52.68}{628.7 \times 1.0501} = \frac{11800.32}{660.20} = 17.8739$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 17.8739 - 14.6804 = 3.1935$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{3.4638}{3.1935} = 1.0846$$

$$R.Q. \text{ Analyzer} = 1.0823$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{175.2 - 174.0}{224.0 - 174} = \frac{1.2}{50} = 0.024$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{52.2}{52.68} \times 1.0476 = 1.037$$

$$V_{O_2(\text{STPD})} = \Delta V_{O_2} \times \frac{60}{L} \times \frac{P_T}{760} \times \frac{492}{T_{\text{Lab}}} = 3.4638 \times \frac{60}{160.1} \times \frac{628.7}{760} \times \frac{492}{559} = 0.978 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 31 Date 3-9-66

Figure 25

Subject D. M. Bar 30.07 mm Hg 763.778 mm Hg
 Work Level Standing T = 79 °F
 Altitude 15,000 ft T_{we} = _____ °F
 Supply Gas Diluter-Demand Reg. P_{CO_2} 0.024 #/cc³
 Run Time 157.7 Sec. V_{spir} 15.90 Liters
 P_{H₂O} In Zero mm Hg V_{in} = 15.0 Liters
 P_{H₂O} Out 25.3 mm Hg P_T = 426 mm Hg

ANALYZER

	P _{CO₂}		P _{O₂} in		P _{O₂} out
1	4.15	4.30	173.5	175.8	178.8
2	4.13	4.34	173.5	174.5	173.5
3	4.13	4.40	173.5	174.0	172.5
4	4.15	4.40	173.5	173.3	172.3
5	4.21	4.35	173.7	172.2	172.0
6	4.25	4.30	173.8	171.5	171.9
7	4.20	4.25	174.0	170.3	171.7
8	4.17	4.17	174.3	169.7	171.7
9	4.15	4.15	174.5	169.4	171.8
10	4.15	4.15	175.2	169.0	171.8
Av	4.17	4.28	Av	174.0	172.0
Av	4.23	cm 33.6 mm Hg	Av	172.8	mm Hg
			Av	126.1	mm Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426 - 172.8 - 0}{426 - 26.1 - 25.3 - 33.6} = \frac{253.2}{241.0} = 1.0506$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{in} = \frac{172.8 \times 15}{426} = \frac{2592.0}{426} = 6.0845$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{126.1 \times 15 \times 1.0506}{426} = \frac{1987.21}{426} = 4.6648$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.0845 - 4.6648 = 1.4197$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{33.6 \times 15 \times 1.0506 \times 1}{426 \times 1.4197} = \frac{529.50}{604.79} = .876$$

BALLOON

Bag Samples

$$P_{CO_2} = 4.20 \text{ cm} = 33.5 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 125.7 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 172.8 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426 - 125.7 - 33.5 - 25.3}{426 - 125.7 - 33.5 - 25.3} = \frac{253.2}{241.3} = 1.0484$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{spir} = \frac{125.7 \times 15.90}{426} = \frac{1998.63}{426} = 4.6916$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{172.8 \times 15.90}{426 \times 1.0484} = \frac{2747.52}{446.62} = 6.1518$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.1518 - 4.6916 = 1.4602$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{1.4197}{1.4602} = .9723$$

$$R.Q. \text{ Analyzer} = .876$$

$$\frac{P_{O_2 \text{ outB}} - P_{O_2 \text{ outA}}}{P_{O_2 \text{ inA}} - P_{O_2 \text{ outA}}} = \frac{125.7 - 126.1}{172.8 - 126.1} = \frac{-0.4}{46.7} = -0.00857$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{15}{15.9} \times 1.0506 = 0.996$$

$$V_{O_2(\text{STD})} = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_T}{P_{\text{Lab}}} = 1.4197 \times \frac{60}{157.7} \times \frac{426}{760} \times \frac{492}{539} = 0.277 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

Run # 32 Date 3-9-66

Figure 26

Subject D. M. Bar 30.07 "Hg 763.778 "Hg
 Work Level Walk OK at 3.5 mph T = 79 °F
 Altitude 15,000 ft T_{re} = _____ °F
 Supply Gas Induter-Demand Bag P_S = .0424 #/ft³
 Run Time 126.2 Sec. V_{spir} 29.38 Liters
 P_{H₂O} In Zero "Hg V_{in} = 28.9 Liters
 P_{H₂O} Out 25.3 "Hg P_T = 426 "Hg

ANALYZER

	P _{CO₂}		P _{O₂} in		P _{O₂} out
1	5.05	4.85	163.0	166.0	105.5
2	5.05	4.75	163.5	166.0	105.5
3	5.05	4.75	164.0	166.0	105.5
4	5.10	4.75	164.0	165.7	105.5
5	5.05	4.75	164.2	165.5	105.5
6	5.05	4.70	164.5	165.3	105.5
7	5.00	4.60	165.0	165.0	105.0
8	5.00	4.55	165.5	164.5	105.0
9	5.00	4.50	166.0	164.2	105.0
10	4.95	4.50	166.0	164.0	105.0
Av	5.03	4.67	164.6	165.2	105.3
Av	cm	40.3 "Hg	164.9 "Hg		105.3 "Hg

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{426 - 164.9 - 0}{426 - 105.3 - 25.3 - 40.3} = \frac{261.10}{255.10} = 1.0235$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}} \times V_{in}}{P_T} = \frac{164.9 \times 28.9}{426} = \frac{4765.61}{426} = 11.1869$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{105.3 \times 28.9 \times 1.0235}{426} = \frac{3114.68}{426} = 7.3115$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 11.1869 - 7.3115 = 3.8754$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T \times \Delta V_{O2}} = \frac{40.3 \times 28.9 \times 1.0235 \times 1}{426 \times 3.8754} = \frac{1192.04}{1650.92} = .722$$

BALLOON

Bag Samples

$$P_{CO2} = \frac{5.25}{cm} = \frac{42.0}{mm \text{ Hg}}$$

$$P_{O2 \text{ out}} = \frac{105.0}{mm \text{ Hg}}$$

$$P_{O2 \text{ in}} = \frac{164.9}{mm \text{ Hg}}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{426 - 164.9 - 0}{426 - 105.3 - 25.3 - 40.3} = \frac{261.10}{255.10} = 1.0292$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{spir} = \frac{10.5 \times 29.38}{426} = \frac{3084.90}{426} = 7.2415$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{164.9 \times 29.38}{426 \times 1.0292} = \frac{4844.76}{438.44} = 11.0500$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 11.0500 - 7.2415 = 3.8085$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{3.8754}{3.8085} = 1.0176$$

$$R.Q. \text{ Analyzer} = .722$$

$$\frac{P_{O2 \text{ out}_B} - P_{O2 \text{ out}_A}}{P_{O2 \text{ in}_A} - P_{O2 \text{ out}_A}} = \frac{105.3 - 105.3}{164.9 - 105.3} = \frac{0.3}{59.6} = -0.005$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{28.9}{29.38} \times 1.0235 = 1.008$$

$$\dot{V}_{O2}(\text{STPD}) = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_T}{P_{Lab}} = 3.8754 \times \frac{60}{126.2} \times \frac{426}{760} = \frac{492}{559} = 0.883 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 33 Date 3-10-66

Figure 27

Subject D. M. Bar 29.96 "Hg 760.984 mm Hg
 Work Level Walk O₂ at 3.5 mph T = 82.5 °F
 Altitude 15,000 ft. T_{ve} = _____ °F
 Supply Gas Diluter-Demand Reg. P_g = .0419 #/ft³
 Run Time 129.1 Sec. V_{spir} 31.82 Liters
 P_{H₂O} In Dry mm Hg V_{in} = 31.4 Liters
 P_{H₂O} Out 88.4 mm Hg P_T = 426 mm Hg

ANALYZER

	P _{CO₂}			P _{O₂} in			P _{O₂} out		
1	4.93	4.90	5.10	157.8	152.2	153.5	97.2	97.7	94.3
2	4.92	4.92	5.10	2 157.8	152.2	153.5	2 97.4	97.6	94.3
3	4.93	4.95	5.05	3 157.8	152.2	153.5	3 97.5	97.5	94.3
4	4.90	5.00	4.98	4 157.8	152.2	153.3	4 97.5	97.3	95.5
5	4.90	5.00	4.90	5 157.7	152.4	153.2	5 97.7	97.0	95.1
6	4.90	5.05		6 157.2	152.7	153.5	6 97.7	96.7	95.1
7	4.85	5.10		7 156.5	153.0	153.3	7 97.7	96.5	96.2
8	4.85	5.10		8 156.2	153.5	153.1	8 97.7	96.3	96.8
9	4.85	5.10		9 156.0	153.8	153.5	9 97.7	96.2	97.5
10	4.82	5.07		10 156.0	152.2	153.3	10 97.8	95.8	95.3
Av	4.89	5.01	5.03	Av 157.1	152.6	153.4	Av 97.6	96.9	95.4
Av	4.98	cm 40.0	mm Hg	Av 154.4	mm Hg		Av 96.6	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426.0 - 154.4 - 0}{426.0 - 96.6 - 28.4 - 40.0} = \frac{280.60}{261.00} = 1.0751$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{in} = \frac{154.4 \times 31.4}{426.0} = \frac{4848.16}{426.0} = 11.3807$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{96.6 \times 31.4 \times 1.0751}{426.0} = \frac{3261.04}{426.0} = 7.6550$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 11.3807 - 7.6550 = 3.7257$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{40.0 \times 31.4 \times 1.0751 \times 1}{426.0 \times 3.7257} = \frac{1350.33}{1587.15} = .8508$$

BALLOON

Bag Samples

$$P_{CO_2} = \underline{5.07} \text{ cm} = \underline{40.6} \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = \underline{96.3} \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = \underline{154.4} \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{280.0}{426.0 - 96.3 - 40.6 - 28.4} = \frac{280.0}{260.7} = 1.0740$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{spir} = \frac{96.3 \times 31.82}{426.0} = \frac{3064.27}{426.0} = 7.1931$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{spir}}{V_{T2}/V_{T1}} = \frac{154.4 \times 31.82}{426.0 \times 1.0740} = \frac{4913.01}{457.52} = 10.7384$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 10.7384 - 7.1931 = 3.5453$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{3.7257}{3.5453} = 1.0508$$

$$R.Q. \text{ Analyzer} = .8508$$

$$\frac{P_{O_2 \text{ out bag}} - P_{O_2 \text{ out anal}}}{P_{O_2 \text{ in A}} - P_{O_2 \text{ out A}}} = \frac{96.3 - 96.6}{154.4 - 96.6} = \frac{-0.3}{57.8} = -.0052$$

$$\frac{V_{anal}}{V_{spir}} \times \frac{V_{T2}}{V_{T1}} = \frac{31.4}{31.82} \times 1.0751 = 1.060$$

$$\dot{V}_{O_2 \text{ (STPD)}} = \Delta V_{O_2} \times \frac{P_T}{C} \times \frac{492}{T_{lab}} = 3.7257 \times \frac{60}{129.1} \times \frac{426}{760} \times \frac{492}{542.5} = 0.879 \text{ liters/min}$$

RESPIRATION ANALYZER

Run # 34 Date 3-11-66

Figure 28

Subject D. M. Bar 29.90 mm Hg 759.460 mm Hg
 Work Level Standing T = 78.5 °F
 Altitude 13,000 Ft T_{we} = °F
 Supply Gas Diluter-Demand Ref ρ_g = .0423 #/ft³
 Run Time 161.0 Sec. V_{spir} 15.0 Liters
 P_{H₂O} In Dry mm Hg V_{in} = (14.65) Liters
 P_{H₂O} Out 24.8 mm Hg P_T = 426 mm Hg

ANALYZER

	P _{CO₂} out				P _{O₂} in				P _{O₂} out				
1	<u>3.90</u>	<u>4.20</u>	<u>3.75</u>	<u>4.10</u>	1	<u>167.5</u>	<u>170.7</u>	<u>174.0</u>	1	<u>128.7</u>	<u>125.3</u>	<u>127.9</u>	<u>130.8</u>
2	<u>3.95</u>	<u>4.10</u>	<u>3.70</u>	<u>4.05</u>	2	<u>167.5</u>	<u>171.1</u>	<u>173.8</u>	2	<u>128.3</u>	<u>125.8</u>	<u>128.0</u>	<u>131.0</u>
3	<u>3.95</u>	<u>4.05</u>	<u>3.65</u>	<u>3.95</u>	3	<u>167.5</u>	<u>171.5</u>	<u>173.3</u>	3	<u>128.1</u>	<u>126.1</u>	<u>128.2</u>	<u>131.3</u>
4	<u>4.00</u>	<u>4.00</u>	<u>3.60</u>	<u>3.90</u>	4	<u>167.5</u>	<u>171.9</u>	<u>172.5</u>	4	<u>128.0</u>	<u>126.3</u>	<u>128.6</u>	<u>131.5</u>
5	<u>4.05</u>	<u>4.00</u>	<u>3.50</u>	<u>3.85</u>	5	<u>167.2</u>	<u>172.1</u>	<u>172.0</u>	5	<u>127.8</u>	<u>126.5</u>	<u>129.1</u>	<u>131.8</u>
6	<u>4.05</u>	<u>4.00</u>	<u>3.50</u>	<u>3.80</u>	6	<u>166.7</u>	<u>172.3</u>	<u>171.5</u>	6	<u>127.5</u>	<u>126.5</u>	<u>129.5</u>	<u>132.0</u>
7	<u>4.10</u>	<u>4.05</u>	<u>3.55</u>	<u>3.85</u>	7	<u>166.3</u>	<u>172.3</u>	<u>170.5</u>	7	<u>127.0</u>	<u>126.5</u>	<u>129.9</u>	<u>132.1</u>
8	<u>4.15</u>	<u>4.05</u>	<u>3.55</u>	<u>3.85</u>	8	<u>166.2</u>	<u>172.6</u>	<u>170.0</u>	8	<u>126.5</u>	<u>126.5</u>	<u>130.0</u>	<u>132.1</u>
9	<u>4.20</u>	<u>4.10</u>	<u>3.60</u>	<u>3.90</u>	9	<u>166.0</u>	<u>173.0</u>	<u>169.5</u>	9	<u>126.1</u>	<u>126.5</u>	<u>130.1</u>	<u>132.1</u>
10	<u>4.05</u>	<u>4.10</u>	<u>3.65</u>	<u>3.90</u>	10	<u>165.9</u>	<u>173.2</u>	<u>168.7</u>	10	<u>126.0</u>	<u>126.5</u>	<u>130.1</u>	<u>132.2</u>
Av	<u>4.04</u>	<u>4.07</u>	<u>3.61</u>	<u>3.92</u>	Av	<u>166.8</u>	<u>172.1</u>	<u>171.7</u>	Av	<u>127.4</u>	<u>126.3</u>	<u>129.1</u>	<u>131.7</u>
Av	<u>3.91</u>	cm	30.2	mm Hg	Av	<u>170.2</u>	mm Hg		Av	<u>128.6</u>	mm Hg		

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H2}}{P_{H1}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{426.0 - 170.2 - 0}{426.0 - 128.6 - 24.8 - 30.2} = \frac{255.80}{252.40} = 1.0553$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}}}{P_T} \times V_{in} = \frac{170.2 \times 14.65}{426.0} = \frac{2493.43}{426.0} = 5.8531$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{128.6 \times 14.65 \times 1.0553}{426.0} = \frac{1988.19}{426.0} = 4.6671$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 5.8531 - 4.6671 = 1.1860$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{30.2 \times 14.65 \times 1.0553}{426.0 \times 1.1860} = \frac{466.896}{505.236} = .9241$$

BALLOON

Bag Samples

$$P_{CO2} = \frac{3.90}{\text{cm}} = \frac{30.0}{\text{mm Hg}}$$

$$P_{O2 \text{ out}} = 127.8 \text{ mm Hg}$$

$$P_{O2 \text{ in}} = 170.2 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{H1}}{P_{H2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{426.0 - 170.2 - 0}{426.0 - 127.8 - 30.0 - 24.8} = \frac{255.80}{253.4} = 1.0509$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{127.8 \times 15.0}{426.0} = \frac{1917}{426.0} = 4.500$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{\text{spir}}}{V_{T2}/V_{T1}} = \frac{170.2 \times 15.0}{426.0 \times 1.0509} = \frac{2553.00}{447.68} = 5.7027$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 5.7027 - 4.500 = 1.2027$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{1.1860}{1.2027} = .9861$$

$$R.Q. \text{ Analyzer} = .9241$$

$$\frac{P_{O2 \text{ out}_B} - P_{O2 \text{ out}_A}}{P_{O2 \text{ in}_A} - P_{O2 \text{ out}_A}} = \frac{127.8 - 128.6}{170.2 - 128.6} = \frac{-0.8}{41.6} = -0.0192$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{14.65}{15.0} \times 1.0553 = 1.030$$

$$V_{O2 \text{ (STPD)}} = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_T}{760} \times \frac{492}{T_{\text{Lab}}} = 1.1860 \times \frac{60}{161} \times \frac{426}{760} \times \frac{492}{538.5} = 0.227 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

Run # 35 Date 3-11-66

Figure 29

Subject D. M. Bar 29.90 mm Hg 759.460 mm Hg
 Work Level Walk 0% at 3.5 mph T = 78.5 °F
 Altitude 15,000 ft T_{ve} = _____ °F
 Supply Gas Diluter Demand Reg. P_g = .0423 #/ft³
 Run Time 151.7 Sec. V_{spir} 36.82 Liters
 P_{H2O} In Dry mm Hg V_{in} = 37.1 Liters
 P_{H2O} Out 24.8 mm Hg P_T = 426 mm Hg

ANALYZER

	P _{CO₂}			P _{O₂} in			P _{O₂} out				
1	<u>4.90</u>	<u>5.00</u>	<u>5.0</u>	1	<u>163.3</u>	<u>164.2</u>	<u>164.3</u>	1	<u>114.1</u>	<u>111.2</u>	<u>112.0</u>
2	<u>4.90</u>	<u>5.00</u>	<u>4.95</u>	2	<u>163.4</u>	<u>164.2</u>	<u>164.6</u>	2	<u>114.0</u>	<u>111.5</u>	<u>112.2</u>
3	<u>4.90</u>	<u>5.00</u>	<u>4.90</u>	3	<u>163.5</u>	<u>164.0</u>	<u>164.9</u>	3	<u>113.7</u>	<u>111.6</u>	<u>112.5</u>
4	<u>5.02</u>	<u>4.95</u>	<u>4.85</u>	4	<u>163.7</u>	<u>164.0</u>	<u>164.8</u>	4	<u>113.2</u>	<u>111.8</u>	<u>112.9</u>
5	<u>5.12</u>	<u>4.92</u>	<u>4.85</u>	5	<u>163.9</u>	<u>164.0</u>	<u>164.7</u>	5	<u>112.3</u>	<u>111.8</u>	<u>113.5</u>
6	<u>5.16</u>	<u>4.95</u>	<u>4.80</u>	6	<u>164.0</u>	<u>164.0</u>	<u>165.2</u>	6	<u>112.0</u>	<u>111.9</u>	<u>113.9</u>
7	<u>5.15</u>	<u>4.93</u>	<u>4.80</u>	7	<u>164.0</u>	<u>164.0</u>	<u>165.0</u>	7	<u>111.3</u>	<u>111.9</u>	<u>114.0</u>
8	<u>5.10</u>	<u>4.95</u>	<u>4.85</u>	8	<u>164.2</u>	<u>164.0</u>	<u>164.5</u>	8	<u>110.2</u>	<u>112.0</u>	<u>114.0</u>
9	<u>5.05</u>	<u>5.00</u>	<u>4.85</u>	9	<u>164.2</u>	<u>163.8</u>	<u>164.2</u>	9	<u>110.0</u>	<u>112.0</u>	<u>114.0</u>
10	<u>5.05</u>	<u>5.00</u>	<u>4.80</u>	10	<u>164.2</u>	<u>163.6</u>	<u>164.5</u>	10	<u>109.7</u>	<u>112.0</u>	<u>114.0</u>
Av	<u>5.04</u>	<u>4.97</u>	<u>4.87</u>	Av	<u>163.8</u>	<u>164.0</u>	<u>164.7</u>	Av	<u>112.1</u>	<u>111.8</u>	<u>113.3</u>
Av	<u>4.96</u>	cm	<u>39.7</u>	mm Hg	Av	<u>164.1</u>	mm Hg	Av	<u>112.6</u>	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{H2O} - P_{CO2 \text{ out}}} = \frac{426.0 - 164.1 - 0}{426 - 112.6 - 24.8 - 39.7} = \frac{261.9}{248.9} = 1.0522$$

$$V_{O2 \text{ in}} = \frac{P_{O2 \text{ in}} \times V_{in}}{P_T} = \frac{164.1 \times 37.1}{426.0} = \frac{6088.11}{426.0} = 14.291$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{112.6 \times 37.1 \times 1.0522}{426.0} = \frac{4395.52}{426.0} = 10.3181$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 14.291 - 10.3181 = 3.9729$$

$$R.Q. = \frac{\Delta V_{CO2}}{\Delta V_{O2}} = \frac{P_{CO2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O2}} = \frac{39.7 \times 37.1 \times 1.0522 \times 1}{426.0 \times 3.9729} = \frac{1549.79}{1692.456} = .9157$$

BALLOON

Bag Samples

$$P_{CO2} = \frac{4.90}{cm} = \frac{39.0}{mm Hg}$$

$$P_{O2 \text{ out}} = \frac{112}{mm Hg}$$

$$P_{O2 \text{ in}} = \frac{164.1}{mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O2 \text{ in}} - P_{H2O \text{ in}}}{P_T - P_{O2 \text{ out}} - P_{CO2 \text{ out}} - P_{H2O}} = \frac{261.9}{426.0 - 112 - 39 - 24.8} = \frac{261.9}{250.2} = 1.0468$$

$$V_{O2 \text{ out}} = \frac{P_{O2 \text{ out}}}{P_T} \times V_{spir} = \frac{112 \times 36.82}{426} = \frac{4123.84}{426.0} = 9.6804$$

$$V_{O2 \text{ in}} = \frac{P_{O2}}{P_T} \times \frac{V_{spir}}{\frac{V_{T2}}{V_{T1}}} = \frac{164.1 \times 36.82}{426 \times 1.0468} = \frac{6042.16}{445.937} = 13.549$$

$$\Delta V_{O2} = V_{O2 \text{ in}} - V_{O2 \text{ out}} = 13.549 - 9.6804 = 3.8686$$

SUMMARY

$$\frac{\Delta V_{O2 \text{ Analyzer}}}{\Delta V_{O2 \text{ Spirometer}}} = \frac{3.9729}{3.8686} = 1.0270$$

$$R.Q. \text{ Analyzer} = .9157$$

$$\frac{P_{O2 \text{ out}_B} - P_{O2 \text{ out}_A}}{P_{O2 \text{ in}_A} - P_{O2 \text{ out}_A}} = \frac{112 - 112.6}{164.1 - 112.6} = \frac{-0.6}{51.5} = -.0117$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{37.1}{36.82} \times 1.0522 = 1.060$$

$$V_{O2}(\text{STPD}) = \Delta V_{O2} \times \frac{60}{C} \times \frac{P_T}{760} \times \frac{492}{T_{\text{Lab}}} = 3.973 \times \frac{60}{151.7} \times \frac{426}{760} \times \frac{492}{538.5} = 0.807 \text{ liters/min}$$

RESPIRATION ANALYZER

MA-66-389

Run # 36 Date 3-23-66

Figure 30

Subject B.A. Bar 29.78 "Hg 756.412 = Hg 2.1 cm. P_T
 Work Level Standing T = 76.5 °F 2.02 cm. T_{sensor}
 Altitude 15,00 Ft T_{ve} = ----- °F
 Supply Gas Diluter-Demand Reg. ρ_g = .0424 #/ft³
 Run Time 120.4 Sec. V_{spir} 16.28 + .6 = 16.88 Liters
 P_{H_2O} In Zero = Hg V_{in} = 15.6 Liters
 P_{H_2O} Out 23.5 = Hg P_T = 426 = Hg

ANALYZER

	P_{CO_2}			P_{O_2} in			P_{O_2} out				
1	<u>2.68</u>	<u>2.60</u>	<u>2.62</u>	1	<u>168.5</u>	<u>169.8</u>	<u>167.8</u>	1	<u>127.7</u>	<u>130.3</u>	<u>128.0</u>
2	<u>2.68</u>	<u>2.63</u>	<u>2.68</u>	2	<u>168.7</u>	<u>169.8</u>	<u>168.0</u>	2	<u>128.0</u>	<u>130.1</u>	<u>128.0</u>
3	<u>2.63</u>	<u>2.65</u>	<u>2.69</u>	3	<u>168.7</u>	<u>169.7</u>	<u>168.2</u>	3	<u>128.3</u>	<u>130.0</u>	<u>127.9</u>
4	<u>2.61</u>	<u>2.66</u>	<u>2.70</u>	4	<u>168.7</u>	<u>169.7</u>	<u>168.5</u>	4	<u>128.5</u>	<u>129.7</u>	<u>127.8</u>
5	<u>2.60</u>	<u>2.68</u>	<u>2.72</u>	5	<u>169.2</u>	<u>169.8</u>	<u>168.9</u>	5	<u>129.0</u>	<u>129.5</u>	<u>127.7</u>
6	<u>2.62</u>	<u>2.70</u>	<u>2.73</u>	6	<u>169.8</u>	<u>169.8</u>	<u>169.3</u>	6	<u>129.3</u>	<u>129.2</u>	<u>127.3</u>
7	<u>2.58</u>	<u>2.72</u>	<u>2.80</u>	7	<u>169.6</u>	<u>169.8</u>	<u>169.5</u>	7	<u>129.5</u>	<u>129.0</u>	<u>127.0</u>
8	<u>2.59</u>	<u>2.70</u>	<u>2.78</u>	8	<u>169.7</u>	<u>169.5</u>	<u>169.5</u>	8	<u>129.7</u>	<u>128.5</u>	<u>126.3</u>
9	<u>2.60</u>	<u>2.70</u>	<u>2.80</u>	9	<u>169.7</u>	<u>168.8</u>	<u>169.5</u>	9	<u>129.8</u>	<u>128.1</u>	<u>126.2</u>
10	<u>2.61</u>	<u>2.69</u>	<u>2.75</u>	10	<u>169.7</u>	<u>168.3</u>	<u>169.3</u>	10	<u>130.0</u>	<u>127.9</u>	<u>125.8</u>
Av	<u>2.620</u>	<u>2.673</u>	<u>2.727</u>	Av	<u>169.2</u>	<u>169.5</u>	<u>168.9</u>	Av	<u>129.0</u>	<u>129.2</u>	<u>127.2</u>
Av	2.67	cm	27.7	mm Hg	Av	169.2	mm Hg	Av	128.5	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426 - 169.2 - 0}{426 - 128.5 - 23.5 - 27.7} = \frac{256.80}{246.3} = 1.0426$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{in}}{P_T} = \frac{169.2 \times 15.6}{426} = \frac{2639.52}{426} = 6.19605$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{in} \times \frac{V_{T2}}{V_{T1}}}{P_T} = \frac{128.5 \times 15.6 \times 1.0426}{426} = \frac{2090.00}{426} = 4.906$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.19605 - 4.906 = 1.290$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{27.7 \times 15.6 \times 1.0426}{426 \times 1.290} = \frac{450.53}{549.50} = 0.820$$

BALLOON

Bag Samples

$$P_{CO_2} = \frac{2.58}{26.1} = \frac{26.1}{26.1} = \text{Hg}$$

$$P_{O_2 \text{ out}} = \frac{128.3}{26.1} = \text{Hg}$$

$$P_{O_2 \text{ in}} = \frac{169.2}{26.1} = \text{Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N1}}{P_{N2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426 - 169.2 - 0}{426 - 128.3 - 26.1 - 23.5} = \frac{256.8}{248.1} = 1.0350$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{128.3 \times 16.88}{426} = \frac{2165.70}{426} = 5.0838$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2}}{P_T} \times \frac{V_{\text{spir}}}{\frac{V_{T2}}{V_{T1}}} = \frac{169.2 \times 16.88}{426 \times 1.0350} = \frac{2856.10}{440.9} = 6.4779$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 6.4779 - 5.0838 = 1.3941$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{1.2900}{1.3941} = .925$$

$$R.Q. \text{ Analyzer} = 0.820$$

$$\frac{P_{O_2 \text{ out B}} - P_{O_2 \text{ out A}}}{P_{O_2 \text{ in A}} - P_{O_2 \text{ out A}}} = \frac{128.3 - 128.5}{169.2 - 128.5} = \frac{-.2}{40.7} = -0.00492$$

$$V_A/V_B \times \frac{V_{T2}}{V_{T1}} = \frac{15.6}{16.88} \times 1.0231 = .946$$

$$\dot{V}_{O_2}(\text{STPD}) = \Delta V_{O_2} \times \frac{60}{\tau} \times \frac{P_T}{760} \times \frac{492}{T_{\text{lab}}} = 1.290 \times \frac{60}{120.4} \times \frac{426}{536.5} = 0.331 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 37 Date 3-23-66

Figure 31

Subject B. A. Bar 29.78 "Hg 756.412 mm Hg
 Work Level Walk 0% at 3.5 mph T = 77.5 °F
 Altitude 15,000 Ft. Pve = ----- °F
 Supply Gas Diluter-Demand Reg. P_g = .0424 #/ft³
 Run Time 127.1 Sec. V_{spir} 28.02 + .6 = 28.62 Liters
 P_{H₂O} In Zero mm Hg V_{in} = 26.4 Liters
 P_{H₂O} Out 23.5 mm Hg P_T = 426 mm Hg

ANALYZER

	P _{CO₂}			P _{O₂} in			P _{O₂} out		
1	3.20	3.29	3.02	159.0	160.5	156.0	105.8	99.0	109.3
2	3.22	3.22	3.06	159.5	160.6	156.0	105.5	99.7	109.5
3	3.24	3.20	3.09	159.7	160.5	156.0	104.8	100.0	109.3
4	3.25	3.20	3.13	159.7	160.3	156.2	104.3	100.5	108.5
5	3.30	3.20	3.12	159.6	160.2	156.5	103.9	100.8	108.2
6	3.30	3.20	3.18	159.3	160.1	156.7	103.7	101.2	108.0
7	3.30	3.12	3.17	158.5	160.0	157.0	102.7	101.5	107.8
8	3.35	3.16	3.10	158.1	160.0	157.2	102.2	101.7	107.6
9	3.32	3.18	3.10	157.8	160.0	157.4	102.0	101.9	107.3
10	3.33	3.18	3.10	157.6	160.0	158.0	101.8	102.0	107.2
Av	3.28	3.20	3.11	Av 158.9	160.2	156.7	Av 103.7	100.8	108.3
Av	3.20	cm 36.0	mm Hg	Av 158.6	mm Hg		Av 102.2	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426 - 158.6 - 0}{426 - 102.2 - 23.5 - 30} = \frac{267.40}{264.30} = 1.0117$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{in} = \frac{158.6 \times 26.4}{426} = \frac{4187.04}{426} = 9.82873$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} = \frac{102.2 \times 26.4 \times 1.0117}{426} = \frac{2729.7}{426} = 6.4077$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 9.82873 - 6.4077 = 3.4210$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{in} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{36 \times 26.4 \times 1.0117}{426 \times 3.4210} = \frac{961.52}{1457.3} = 0.660$$

BALLOON

Bag Samples

$$P_{CO_2} = 3.23 \text{ cm} = 36.3 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 100.5 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 158.6 \text{ mm Hg}$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{H_2O}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426 - 158.6 - 0}{426 - 100.5 - 36.3 - 23.5} = \frac{265.70}{265.08} = 1.00233$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{spir} = \frac{100.5 \times 28.62}{426} = \frac{2876.31}{426} = 6.75190$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{spir}}{\frac{V_{T2}}{V_{T1}}} = \frac{158.6 \times 28.62}{426 \times 1.00233} = \frac{4539.13}{426.99} = 10.63052$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 10.63052 - 6.75190 = 3.87862$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{3.56317}{3.87862} = .91866$$

$$R.Q. \text{ Analyzer} = 0.660$$

$$\frac{P_{O_2 \text{ outB}} - P_{O_2 \text{ outA}}}{P_{O_2 \text{ inA}} - P_{O_2 \text{ outA}}} = \frac{100.5 - 102.2}{158.6 - 102.2} = \frac{-1.7}{56.4} = -.03014$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{26.4}{28.62} \times .98927 = \frac{26.1167}{28.62} = .91253$$

$$\dot{V}_{O_2}(\text{STPD}) = \Delta V_{O_2} \times \frac{60}{T} \times \frac{P_T}{P_{\text{Lab}}} \times \frac{492}{T_{\text{Lab}}} = 3.4210 \times \frac{60}{1221} \times \frac{426}{760} \times \frac{492}{537.5} = 0.828 \text{ Liters/min.}$$

RESPIRATION ANALYZER

KA-66-389

Run # 38 Date 3-24-66

Figure 32

Subject D.M. Bar 29.75 "Hg 755.650 mm Hg
 Work Level Standing T = 72 °F
 Altitude 15,000 Ft. Tve = 0.0427 °F
 Supply Gas Diluter-Demand Reg. PG = 0.0427 #/ft³
 Run Time 139.5 Sec. V_{spir} 14.66 + .6 = 15.26 Liters
 P_{H₂O} In ----- mm Hg Vin = 13.10 Liters
 P_{H₂O} Out 20.2 mm Hg P_T = 426 mm Hg

ANALYZER

P _{CO₂}			P _{O₂} in			P _{O₂} out					
1	<u>3.17</u>	<u>3.00</u>	<u>3.11</u>	1	<u>163.8</u>	<u>160.0</u>	<u>166.0</u>	1	<u>115.9</u>	<u>118.7</u>	<u>118.0</u>
2	<u>3.12</u>	<u>3.00</u>	<u>3.09</u>	2	<u>164.0</u>	<u>159.5</u>	<u>166.0</u>	2	<u>116.1</u>	<u>118.7</u>	<u>118.0</u>
3	<u>3.13</u>	<u>3.00</u>	<u>3.10</u>	3	<u>164.0</u>	<u>159.2</u>	<u>165.8</u>	3	<u>116.2</u>	<u>118.7</u>	<u>118.0</u>
4	<u>3.17</u>	<u>2.98</u>	<u>3.10</u>	4	<u>164.2</u>	<u>158.5</u>	<u>165.8</u>	4	<u>116.3</u>	<u>118.7</u>	<u>118.0</u>
5	<u>3.20</u>	<u>2.85</u>	<u>3.11</u>	5	<u>164.5</u>	<u>158.1</u>	<u>165.8</u>	5	<u>116.3</u>	<u>118.8</u>	<u>118.0</u>
6	<u>3.20</u>	<u>2.93</u>	<u>3.13</u>	6	<u>165.0</u>	<u>158.0</u>	<u>166.0</u>	6	<u>116.2</u>	<u>119.2</u>	<u>118.0</u>
7	<u>3.15</u>	<u>2.92</u>	<u>3.15</u>	7	<u>165.3</u>	<u>157.5</u>	<u>166.0</u>	7	<u>116.1</u>	<u>119.4</u>	<u>118.0</u>
8	<u>3.17</u>	<u>2.93</u>	<u>3.17</u>	8	<u>165.5</u>	<u>157.0</u>	<u>166.0</u>	8	<u>116.0</u>	<u>119.8</u>	<u>118.0</u>
9	<u>3.15</u>	<u>2.95</u>	<u>3.18</u>	9	<u>165.8</u>	<u>156.5</u>	<u>166.0</u>	9	<u>115.8</u>	<u>119.9</u>	<u>118.0</u>
10	<u>3.10</u>	<u>2.96</u>	<u>3.20</u>	10	<u>165.9</u>	<u>156.2</u>	<u>166.0</u>	10	<u>116.2</u>	<u>120.0</u>	<u>118.0</u>
Av	<u>3.16</u>	<u>2.95</u>	<u>3.13</u>	Av	<u>164.8</u>	<u>158.1</u>	<u>165.9</u>	Av	<u>116.1</u>	<u>119.2</u>	<u>118.0</u>
Av	<u>3.08</u>	cm <u>34.0</u>	mm Hg	Av	<u>162.9</u>	mm Hg		Av	<u>117.8</u>	mm Hg	

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O \text{ out}} - P_{CO_2 \text{ out}}} = \frac{426 - 162.9 - 0}{426 - 117.8 - 20.2 - 34} = \frac{263.1}{254.0} = 1.03582$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times V_{T1} = \frac{162.9 \times 13.10}{426} = \frac{2133.99}{426} = 5.00936$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{T1} \times \frac{V_{T2}}{V_{T1}} = \frac{117.8 \times 13.10 \times 1.03582}{426} = \frac{1598.46}{426} = 3.75225$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 5.00936 - 3.75225 = 1.25711$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{T1} \times \frac{V_{T2}}{V_{T1}} \times \frac{1}{\Delta V_{O_2}} = \frac{34 \times 13.10 \times 1.03582 \times 1}{426 \times 1.25711} = \frac{461.35}{535.53} = .86148$$

BALLOON

Bag Samples

$$P_{CO_2} = \frac{2.9}{31.0} = 0.0935$$

$$P_{O_2 \text{ out}} = \frac{116.0}{426} = 0.2723$$

$$P_{O_2 \text{ in}} = \frac{162.9}{426} = 0.3824$$

$$\frac{V_{T2}}{V_{T1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O \text{ out}}} = \frac{426 - 162.9 - 0}{426 - 116 - 31 - 20.2} = \frac{263.1}{236.8} = 1.10175$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{116 \times 15.26}{426} = \frac{1770.16}{426} = 4.15530$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}}}{P_T} \times \frac{V_{\text{spir}}}{\frac{V_{T2}}{V_{T1}}} = \frac{162.9 \times 15.26}{426 \times 1.10175} = \frac{2485.9}{469.3} = 5.29703$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 5.29703 - 4.15530 = 1.14173$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{1.257}{1.142} = 1.10$$

$$R.Q. \text{ Analyzer} = .86148$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{116.0 - 117.8}{162.9 - 117.8} = \frac{-1.8}{45.1} = -0.0399$$

$$\frac{V_A}{V_B} \times \frac{V_{T2}}{V_{T1}} = \frac{13.10}{15.26} \times 1.036 = 0.89$$

$$\dot{V}_{O_2}(\text{STPD}) = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_T}{P_{\text{lab}}} = 1.25711 \times \frac{60}{139.5} \times \frac{426}{760} \times \frac{492}{532} = 0.281 \text{ liters/min}$$

RESPIRATION ANALYZER

NA-66-389

Run # 39 Date 3-24-66

Figure 33

Subject D.M. Bar 29.75 "Hg 755.650 = Hg
 Work Level Walk %
 Altitude 15,000 FT
 Supply Gas Diluter-Demand Reg.
 Run Time 156.0 Sec.
 $V_{\text{spir}} = 33.26 + .62 = 33.86$ Liters
 $g = 0.0426$ #/ft³
 $V_{\text{in}} = 33.60$ Liters
 $P_{\text{T}} = 426$ mm Hg
 $P_{\text{H}_2\text{O}}$ In = mm Hg
 $P_{\text{H}_2\text{O}}$ Out = 20.7 mm Hg

ANALYZER

P_{CO_2}					P_{O_2} in			P_{O_2} out					
1	<u>3.55</u>	<u>3.62</u>	<u>3.70</u>	<u>3.60</u>	1	<u>160.7</u>	<u>161.8</u>	<u>160.0</u>	1	<u>104.0</u>	<u>101.8</u>	<u>98.7</u>	<u>98.3</u>
2	<u>3.55</u>	<u>3.60</u>	<u>3.70</u>	<u>3.58</u>	2	<u>160.7</u>	<u>161.9</u>	<u>160.1</u>	2	<u>103.9</u>	<u>101.8</u>	<u>98.5</u>	<u>98.3</u>
3	<u>3.62</u>	<u>3.60</u>	<u>3.70</u>	<u>3.60</u>	3	<u>160.7</u>	<u>161.9</u>	<u>160.1</u>	3	<u>103.7</u>	<u>101.8</u>	<u>98.2</u>	<u>98.3</u>
4	<u>3.63</u>	<u>3.60</u>	<u>3.70</u>	<u>3.60</u>	4	<u>160.7</u>	<u>161.9</u>	<u>160.2</u>	4	<u>103.2</u>	<u>101.9</u>	<u>98.1</u>	<u>98.3</u>
5	<u>3.67</u>	<u>3.57</u>	<u>3.68</u>	<u>3.58</u>	5	<u>160.7</u>	<u>161.9</u>	<u>160.2</u>	5	<u>102.5</u>	<u>102.0</u>	<u>98.0</u>	<u>98.3</u>
6	<u>3.68</u>	<u>3.60</u>	<u>3.67</u>	<u>3.59</u>	6	<u>160.5</u>	<u>161.9</u>	<u>160.3</u>	6	<u>102.2</u>	<u>102.1</u>	<u>97.9</u>	<u>98.3</u>
7	<u>3.67</u>	<u>3.59</u>	<u>3.69</u>	<u>3.55</u>	7	<u>160.3</u>	<u>161.9</u>	<u>160.2</u>	7	<u>102.1</u>	<u>102.2</u>	<u>97.8</u>	<u>98.3</u>
8	<u>3.62</u>	<u>3.60</u>	<u>3.63</u>	<u>3.53</u>	8	<u>160.1</u>	<u>161.5</u>	<u>160.2</u>	8	<u>102.0</u>	<u>102.2</u>	<u>97.5</u>	<u>98.3</u>
9	<u>3.65</u>	<u>3.50</u>	<u>3.60</u>	<u>3.55</u>	9	<u>160.0</u>	<u>161.0</u>	<u>160.1</u>	9	<u>102.0</u>	<u>102.2</u>	<u>97.4</u>	<u>98.3</u>
10	<u>3.60</u>	<u>3.60</u>	<u>3.60</u>	<u>3.53</u>	10	<u>160.0</u>	<u>160.5</u>	<u>160.0</u>	10	<u>101.9</u>	<u>102.2</u>	<u>97.5</u>	<u>98.3</u>
Av	<u>3.62</u>	<u>3.59</u>	<u>3.66</u>	<u>3.57</u>	Av	<u>160.4</u>	<u>161.7</u>	<u>160.1</u>	Av	<u>102.7</u>	<u>101.9</u>	<u>98.0</u>	<u>98.3</u>
Av	<u>3.61</u>	cm	<u>43.0</u>	mm Hg	Av	<u>160.8</u>	mm Hg		Av	<u>100.2</u>	mm Hg		

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{H_2O} - P_{CO_2 \text{ out}}} = \frac{426 - 160.8 - 0}{426 - 100.2 - 20.7 - 43} = \frac{265.20}{262.10} = 1.01182$$

$$V_{O_2 \text{ in}} = \frac{P_{O_2 \text{ in}} \times V_{\text{in}}}{P_T} = \frac{160.8 \times 33.60}{426} = \frac{5402.88}{426} = 12.68281$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}} \times V_{\text{in}} \times \frac{V_{T_2}}{V_{T_1}}}{P_T} = \frac{100.2 \times 33.60 \times 1.01182}{426} = \frac{3406.51}{426} = 7.99650$$

$$\Delta V_{O_2} = V_{O_2 \text{ in}} - V_{O_2 \text{ out}} = 12.68281 - 7.99650 = 4.68631$$

$$R.Q. = \frac{\Delta V_{CO_2}}{\Delta V_{O_2}} = \frac{P_{CO_2 \text{ out}}}{P_T} \times V_{\text{in}} \times \frac{V_{T_2}}{V_{T_1}} \times \frac{1}{\Delta V_{O_2}} = \frac{43 \times 33.60 \times 1.01182 \times 1}{426 \times 4.68631} = \frac{1461.88}{1996.37} = .73226$$

BALLOON

Bag Samples

$$P_{CO_2} = 3.55 \text{ cm} = 42.2 \text{ mm Hg}$$

$$P_{O_2 \text{ out}} = 100.0 \text{ mm Hg}$$

$$P_{O_2 \text{ in}} = 160.8 \text{ mm Hg}$$

$$\frac{V_{T_2}}{V_{T_1}} = \frac{P_{N_2}}{P_{N_2}} = \frac{P_T - P_{O_2 \text{ in}} - P_{H_2O \text{ in}}}{P_T - P_{O_2 \text{ out}} - P_{CO_2 \text{ out}} - P_{H_2O}} = \frac{426 - 160.8 - 0}{426 - 100 - 42.2 - 20.7} = \frac{265.2}{263.1} = 1.00798$$

$$V_{O_2 \text{ out}} = \frac{P_{O_2 \text{ out}}}{P_T} \times V_{\text{spir}} = \frac{100 \times 33.86}{426} = \frac{3386.0}{426} = 7.94835$$

$$V_{CO_2 \text{ in}} = \frac{P_{CO_2}}{P_T} \times \frac{V_{\text{spir}}}{V_{T_2} - V_{T_1}} = \frac{160.8 \times 33.86}{426 \times 1.00798} = \frac{5444.69}{429.40} = 12.67976$$

$$\Delta V_{CO_2} = V_{CO_2 \text{ in}} - V_{O_2 \text{ out}} = 12.67976 - 7.94835 = 4.73141$$

SUMMARY

$$\frac{\Delta V_{O_2 \text{ Analyzer}}}{\Delta V_{O_2 \text{ Spirometer}}} = \frac{4.68631}{4.73141} = .99046$$

$$R.Q. \text{ Analyzer} = .73226$$

$$\frac{P_{O_2 \text{ out}_B} - P_{O_2 \text{ out}_A}}{P_{O_2 \text{ in}_A} - P_{O_2 \text{ out}_A}} = \frac{100.0 - 100.2}{160.8 - 100.2} = \frac{.2}{60.6} = -.00492$$

$$\frac{V_A}{V_B} \times \frac{V_{T_2}}{V_{T_1}} = \frac{33.6}{33.86} \times 1.01182 = 1.005$$

$$\dot{V}_{O_2}(\text{STPD}) = \Delta V_{O_2} \times \frac{60}{C} \times \frac{P_T}{760} = 4.686 \times \frac{60}{156} \times \frac{426}{760} \times \frac{492}{333} = 0.933 \text{ liters/min}$$

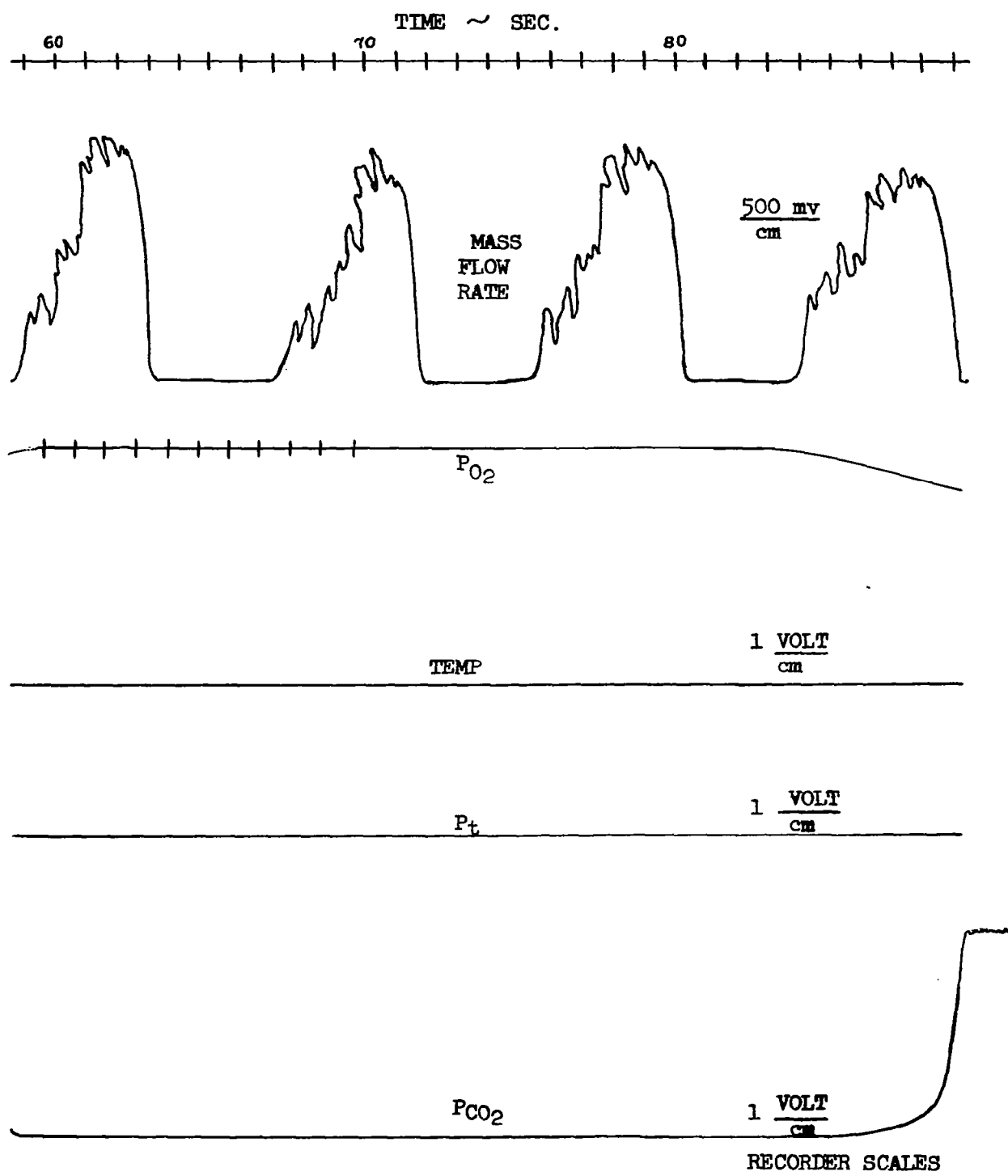


Figure 34. Example of Typical Data Trace

TIME RECORD

FLOW

3

2 1.80 CM = 141.0 mm Hg P_{O_2}

1

0 cm

TEMPERATURE

P_t

4.63 cm = 36.8 mm Hg P_{CO_2}



Figure 35. Example of Balloon Gas Sample Trace

DISCUSSION OF DATA

Figure 36 presents a summary of the data taken on Runs 20 through 39. These data are felt to be most representative of the respiratory analyzer performance and represent the final improvements in instrumentation and experimental techniques. Earlier runs are not covered herein as they are not considered of equal significance and have been previously reported in Monthly Progress Letter No. 4.

Each of the runs is itemized by run number, the experimental subject, the altitude, the composition of the incoming air, and the work level effort of the subject. For each of these runs the following data are tabulated:

1. Percent error in Oxygen Uptake - This column represents the difference between oxygen consumption as computed by the analyzer and the consumption computed from a collected sample of the respiratory products. A plus value indicates that the analyzer showed a higher consumption than the "bag analysis" (balloon collected sample).
2. R.Q. - This column presents the respiratory quotient of the subject as computed from the respiratory analyzer data.
3. Percent Error in ΔP_{O_2} - The ΔP_{O_2} error is the difference between exhaled partial pressure of oxygen measured in the balloon and the partial pressure of oxygen measured in the analyzer, expressed as a percent of the difference between inhaled and exhaled partial pressure of oxygen as measured by the analyzer.
4. Percent Volume Error - This column shows the percent difference between the volume as determined from the mass flowmeter and the volume as measured by the spirometer as corrected for the ratio of the V_{T_2}/V_{T_1} . A positive value indicates that the mass flowmeter gave a higher indication than the spirometer.
5. P_{O_2} Error - This column presents the discharge partial pressure of oxygen measured by the analyzer minus the discharge partial pressure of oxygen measured in the balloon expressed as a percent of oxygen partial pressure in the balloon.

6. Oxygen Uptake - This column presents the oxygen uptake of the subject corrected to standard conditions (32°F, 760 mm Hg pressure, dry) expressed in liters per minute.

All but three of the 20 runs demonstrated accuracy in oxygen consumption measurements within the desired range of ± 10 percent. Run 27 was extremely out of line and showed a difference of 36 percent. After careful examination of the data it was concluded that this error was probably caused by improper operator technique. The line through which the balloon sample is withdrawn was teed to the line from the inspiratory mixing chamber. Failure of the operator to tightly seat the valve from the mixing chamber while analyzing the balloon sample could have caused this error. The test setup was changed to eliminate this possibility for all subsequent runs. If we choose to ignore the 36 percent reading on the basis of faulty operator technique the average positive error is 6.4 percent, the average negative error 6.67 percent, and the arithmetic mean error 0.09 percent. Of the remaining two runs which exceeded an error of ± 10 percent, Run 24 (-16.2 percent) was conducted at sea level using a gas mixture of 40 percent oxygen and 60 percent nitrogen. In examining the data to discover the reason for this high error, an interesting fact evident from earlier error analyses became apparent. The volume checks were reasonable, being within 4.7 percent, and the P_{O_2} out readings checked well within the desired 1 percent accuracy. The equation relating ΔV_{O_2} for the analyzer to ΔV_{O_2} for the balloon sample can be written in the following form to explain this effect:

$$\frac{\Delta V_{O_2 \text{ analyzer}}}{\Delta V_{O_2 \text{ bag}}} = \frac{V_{in \text{ analyzer}}}{V_{in \text{ bag}}} \frac{P_{O_2 \text{ in}} - \frac{V_{T_2}}{V_{T_1}} P_{O_2 \text{ out analyzer}}}{P_{O_2 \text{ in}} - \frac{V_{T_2}}{V_{T_1}} P_{O_2 \text{ out bag}}} \quad (13)$$

Here, we can see that if $P_{O_2 \text{ out}}$ has a large absolute value, small differences in the ratios of V_{T_2}/V_{T_1} will have a large effect on the term

$\left(P_{O_2 \text{ in}} - \frac{V_{T_2}}{V_{T_1}} P_{O_2 \text{ out}} \right)$. In this particular run, the value of $P_{O_2 \text{ out}}$

* 40% Oxygen-60% Nitrogen
 ** DILUTER-DEMAND REGULATOR

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Figure 36

					1	2	3	4	5	6	
RUN NO.	SUBJECT	WORK LEVEL	ALTITUDE (FT)	ATMOSPHERE	% ERROR IN O ₂ UPTAKE	R.Q.	% ERROR IN PO ₂	% VOLUME ERROR	% PO ₂ ERROR	OXYGEN UPTAKE LITER/MLN (STPD)	COMMENTS
20	L.B.	Walk	S.L.	Air	+8.4	1.0	-1.4	-6.0	-.42	0.843	
21	W.A.	Stand	S.L.	Air	+11.8	1.03	+8.2	-1.6	-2.0	0.346	
22	W.A.	Walk	S.L.	Air	+2.8	.87	+0.8	+2.2	-2.2	0.763	
23	L.B.	Stand	S.L.	Air	-4.5	1.05	+0.3	-4.0	-.08	0.313	
24	L.B.	Stand	S.L.	40-60*	-16.2	.76	-4.5	-4.7	-.71	0.308	
25	L.B.	Stand	10,000	D.D.**	-6.3	.97	+2.8	+4.0	-.61	0.263	
26	L.B.	Walk	10,000	D.D.	+7.7	.83	-0.8	+8.4	+.28	0.840	
27	L.B.	Stand	15,000	D.D.	+36.0	1.17	+10.9	+1.5	-2.8	0.252	Faulty operator technique
28	L.B.	Walk	15,000	D.D.	+3.9	.82	-3.5	+13.0	+1.6	0.90	
29	L.B.	Stand	5,000	D.D.	-4.8	1.20	-2.49	+2.50	+.41	0.295	
30	L.B.	Walk	5,000	D.D.	+10.0	1.08	+2.4	+3.7	-.69	0.978	
31	D.M.	Stand	15,000	D.D.	-3.5	.88	-0.9	+0.4	-.32	0.277	
32	D.M.	Walk	15,000	D.D.	+2.7	.72	-0.5	+0.8	+.29	0.943	
33	D.M.	Walk	15,000	D.D.	+5.1	.85	-0.5	+6.0	+.31	0.879	
34	D.M.	Stand	15,000	D.D.	+5.3	.92	-1.9	+3.0	+.68	0.227	
35	D.M.	Walk	15,000	D.D.	+2.7	.92	-1.2	+6.0	+.53	0.807	
36	W.A.	Stand	15,000	D.D.	-7.5	.82	-0.5	-5.4	+.16	0.331	IR P _{CO2} Sensor
37	W.A.	Walk	15,000	D.D.	-8.1	.66	-3.0	-8.7	+1.7	0.828	" " "
38	D.M.	Stand	15,000	D.D.	+10.0	.86	-4.0	-11.0	+1.55	0.281	" " "
39	D.M.	Walk	15,000	D.D.	-1.0	.73	-0.5	+0.5	+0.2	0.933	" " "

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was equal to about 268 mm Hg as compared to about 160 mm Hg when using air or the diluter-demand regulator. Furthermore, the differences measured in all parameters, including P_{CO_2} , between the analyzer and balloon samples all tended to influence the difference in the same direction.

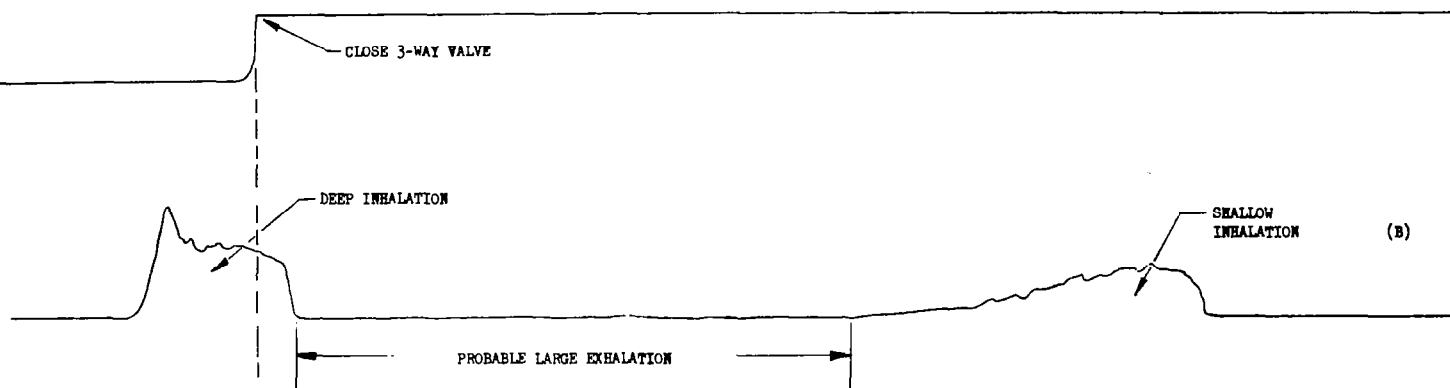
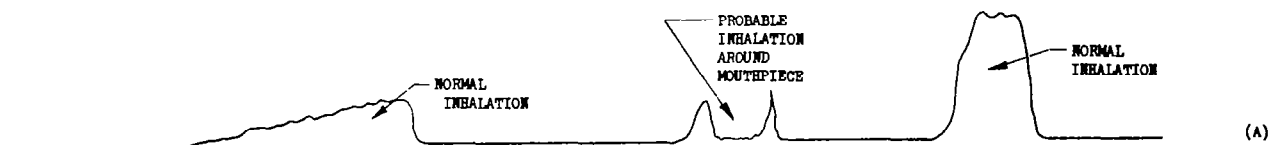
The significance of the R.Q. values computed for these runs is questionable since no control was used in selecting or readying the subjects for test. Runs were made before and after meals and with no control of diet. In some instances, the subject (L.B.) had just completed strenuous exercise on the treadmill for another test program. The subject (D.M.) was notably relaxed during most of his runs and once actually dozed between runs while still breathing from the mouthpiece. In general, the R.Q. values serve as a confirmation that the oxygen consumption values are not grossly in error. The R.Q. can also be used to further the argument that in Run #27 the error is in the bag sample analysis rather than in the analyzer determination. R.Q. computed from the bag sample would indicate the extremely improbable R.Q. of 0.48.

Although considerable effort was expended in steady-state and pulsatile calibration of flowmeters, the best check is probably the comparison of integrated flowmeter values with spirometer measured values under actual operating conditions. Out of twenty runs, four exceeded a ± 6 percent difference. All but six were on the "plus" side. The average "plus" difference was 4.23 percent, the average "minus" difference was 5.7 percent, and the arithmetic mean difference was +1.25 percent. The largest difference (+13 percent) was measured on Run #28. No reasonable explanation for this large discrepancy could be discovered. It should be remembered, however, that the error could have been in the spirometry and this "outside" value does not necessarily indicate erratic operation of the flowmeter. Run 38 also showed a large error (-11 percent). Examination of the data traces in this case offered some clues as to probable reasons. Figure 37a shows a trace of the mass flowmeter during the first part of the run. Between the normal appearing breaths we see an unusual breathing pattern. It is believed that the subject relaxed his bite on the mouthpiece and inhaled largely from the surrounding atmosphere rather than through the flowmeter.

FLOWMETER TRACE COPIES FROM RUN 38
SHOWING POSSIBLE DISCREPANCIES BETWEEN
FLOWMETER AND SPIROMETER VALUES

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Figure 37



This could have influenced the reading by as much as 6 or 7 percent. In addition, the last inhalation measured by the flowmeter before switching the sample valve was very shallow as can be seen in figure 37b. The subsequent exhalation which was collected in the balloon was probably much larger since the next inhalation was greater than normal. This could contribute another 2 or 3 percent.

The data shown in column 5 indicates that the P_{O_2} measured in the expiratory mixing chamber checks the collected sample with ± 1 percent for fifteen of the nineteen satisfactory runs. In the remaining four, the difference did not exceed ± 2 percent. In Run #21, the P_{O_2} in the balloon read higher than any value measured from the mixing chamber during the run. It is quite possible that this discrepancy was caused by the same faulty operator technique discussed for Run #27.

The values of oxygen uptake of the standing subjects varied between 0.263 and 0.346 liters per minute. With the subjects walking the treadmill at 3.5 miles per hour the uptake varied from 0.763 to 0.978 liters per minute. Again, it should be emphasized that no control was exercised over the condition of the subjects at the time of test.

For the runs in which the composition of the incoming gas was known, the P_{O_2} sensor output was adjusted on the Offner Recorder to the proper reading. Sampling during the tests always checked the initial input value. For runs with the diluter-demand regulator, the Offner was set to read correctly on sea level air. The output of the demand regulator was found to drift somewhat during the runs. This can be seen by examining the " P_{O_2} in" readings on the data sheets (figures 14 through 33). General curves of typical diluter-demand regulator performance are shown for reference in figures 38 and 39.

Runs 26, 29, and 30 required shifting of the zeros on P_{O_2} after the chamber was taken to altitude. Thus the readings on the data sheets are not in units of P_{O_2} and must be converted using figures 40 and 41.

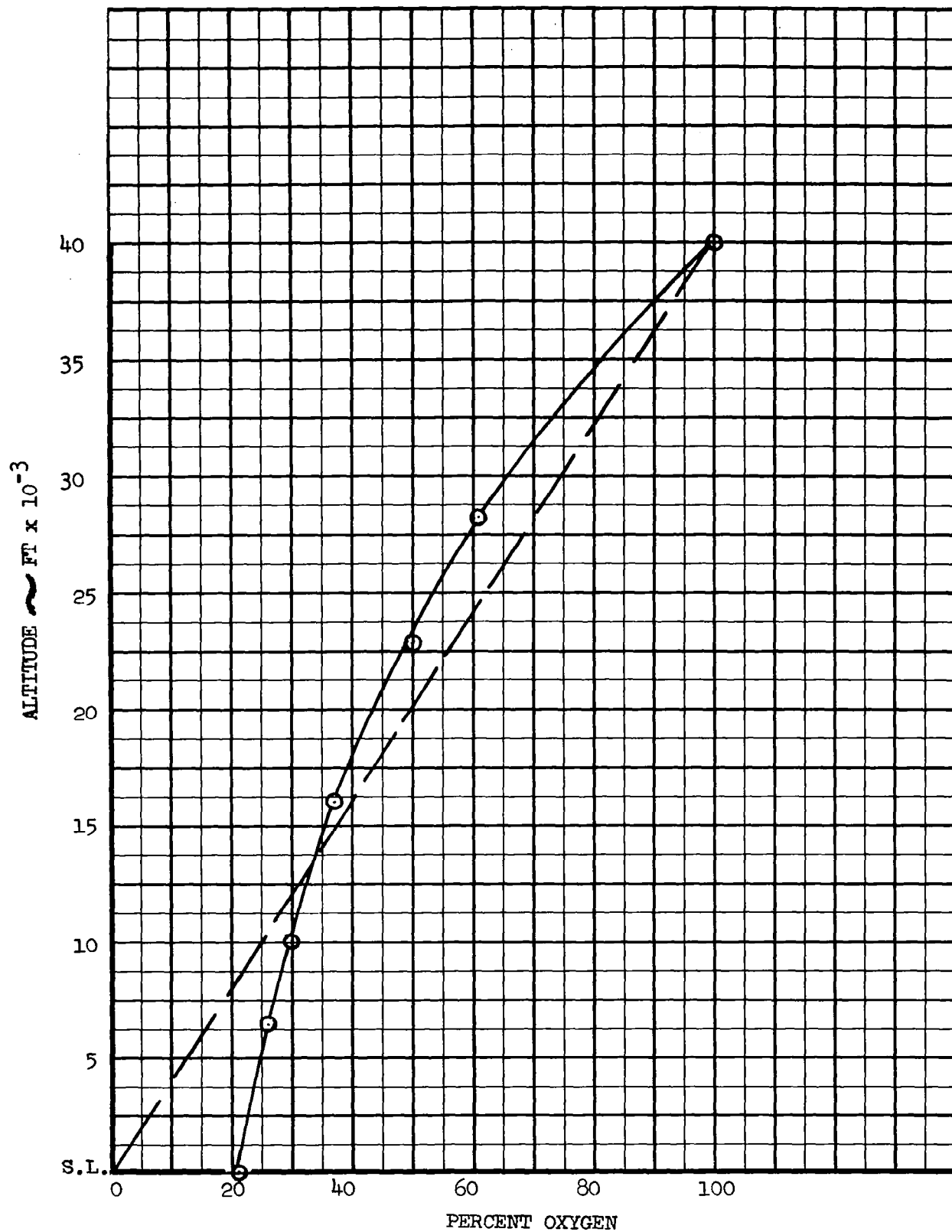


Figure 38. Diluter Demand Oxygen Regulator O_2 Mixing Percent.

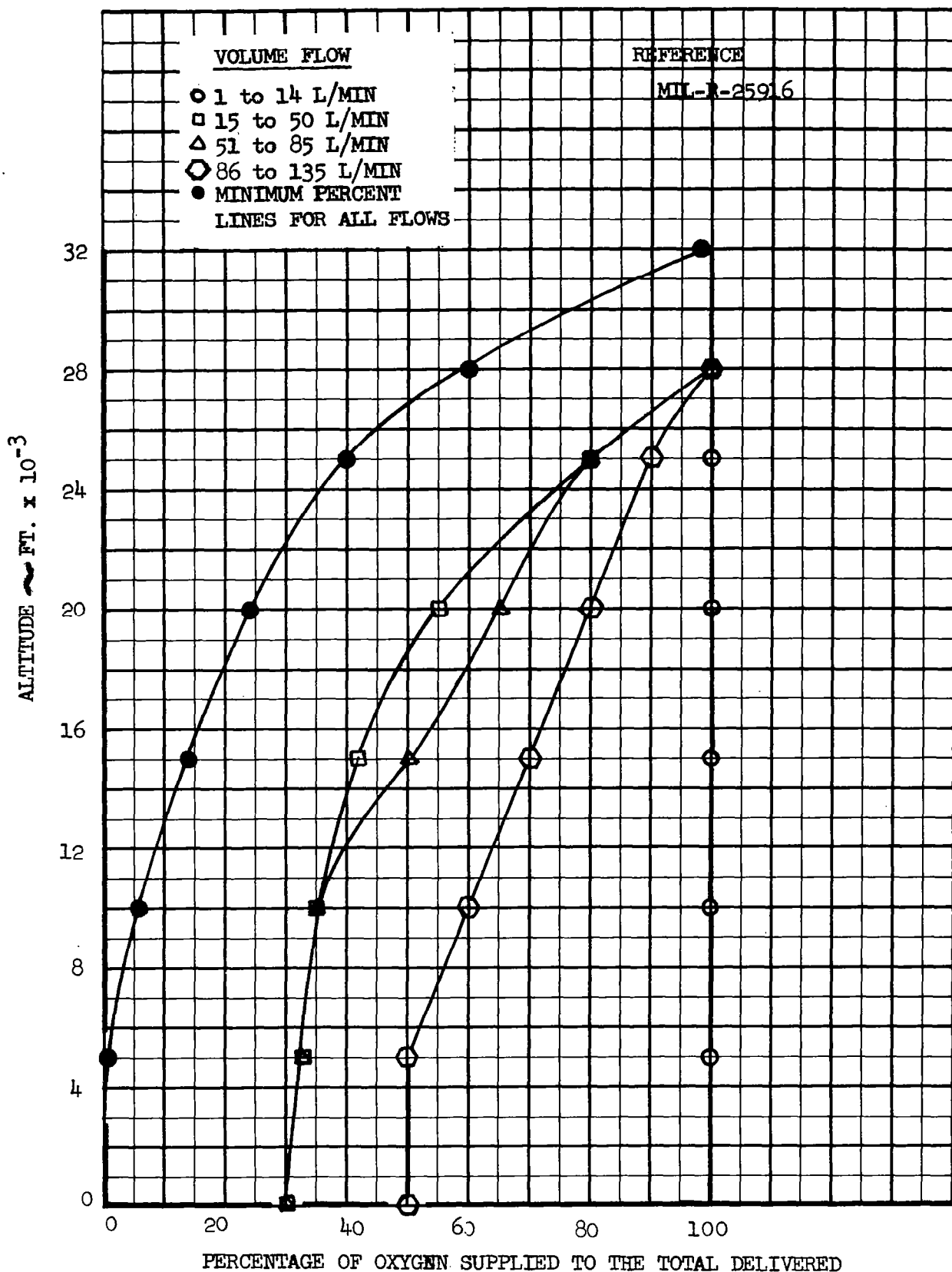


Figure 39. Diluter-Demand Oxygen Regulator

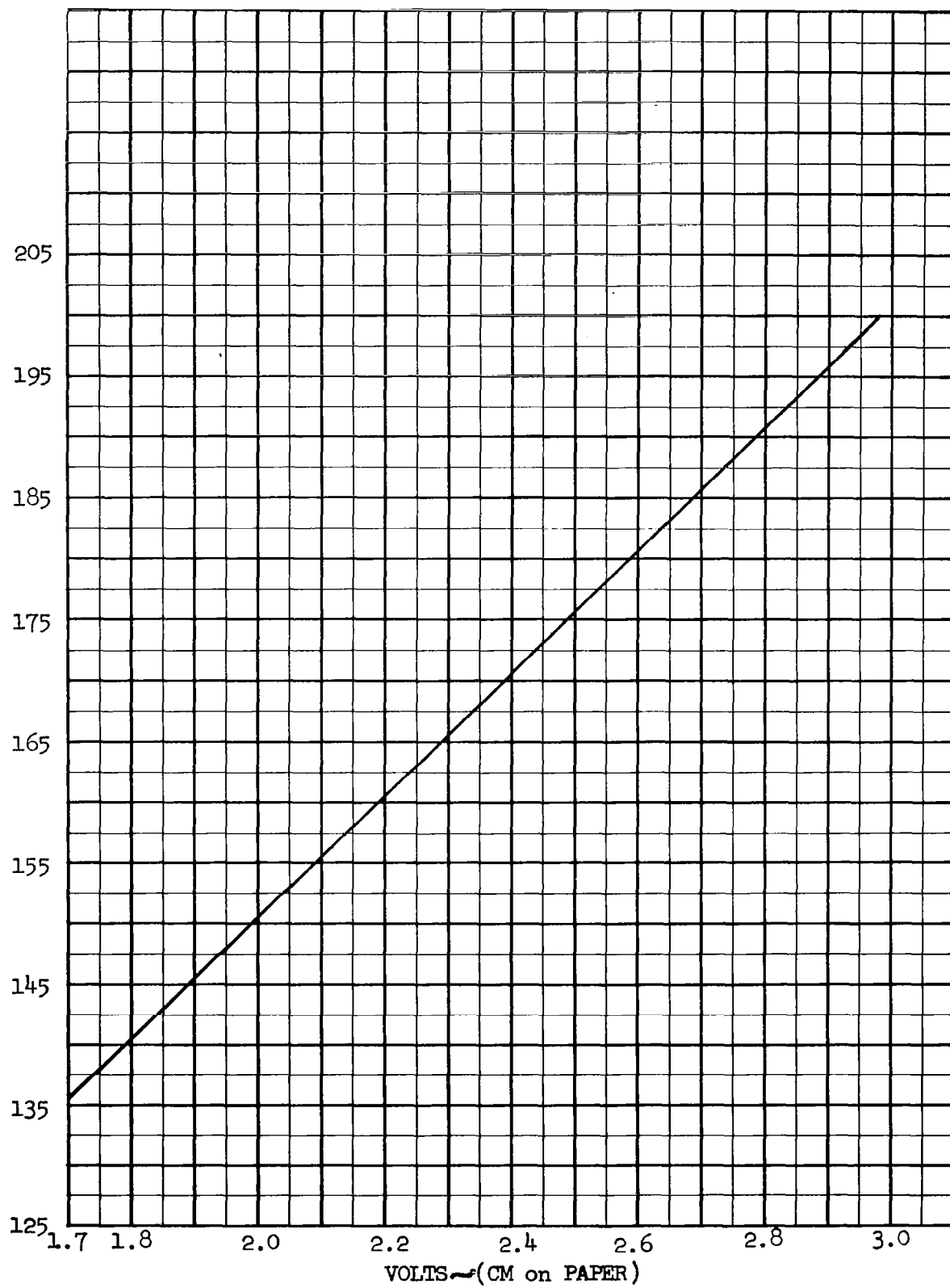


Figure 40. Recorder Conversion Curve For PO_2

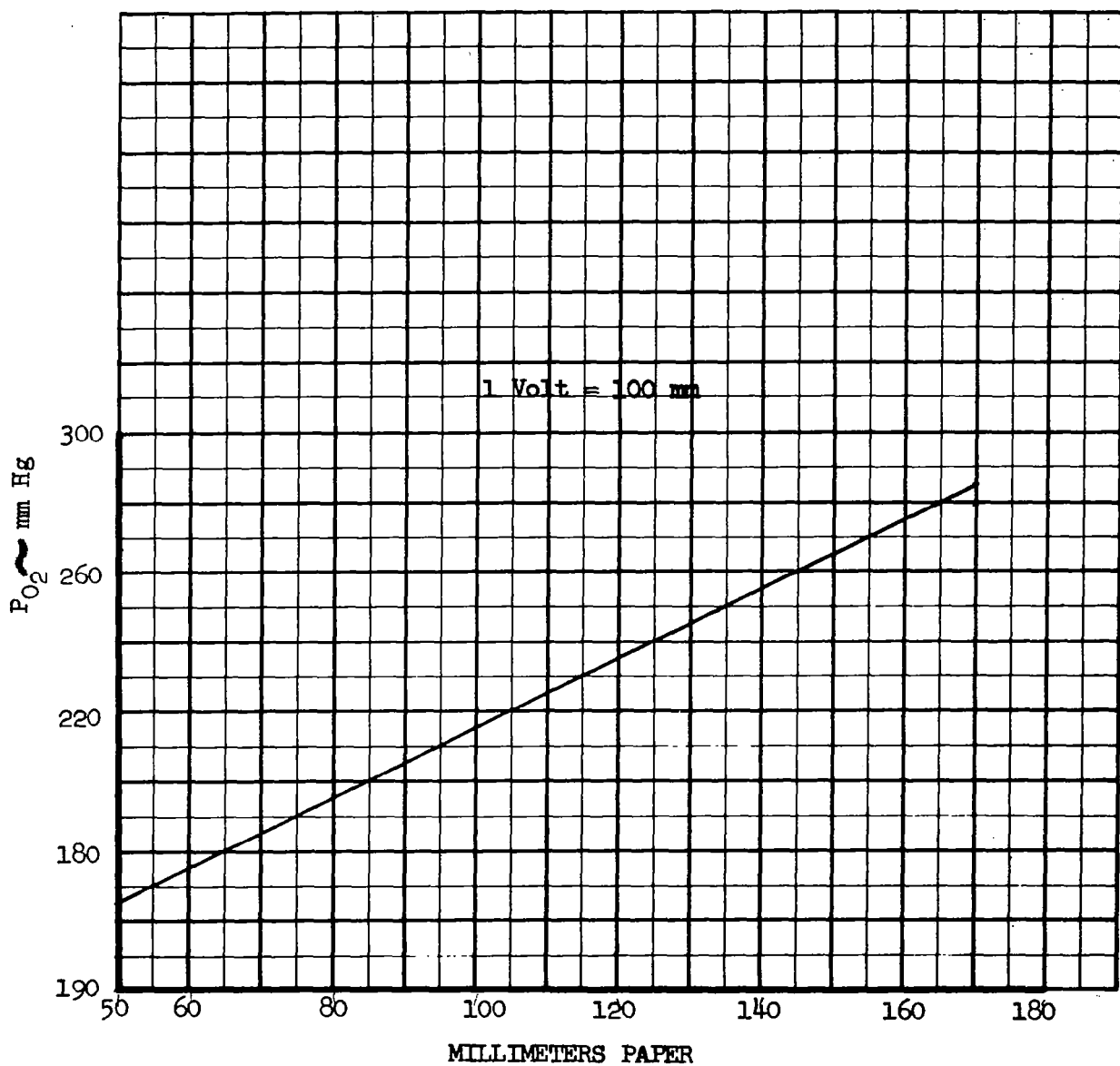


Figure 41. Recorder Calibration for Runs No. 29 and 30.

INSTRUMENTATION CALIBRATION

FLOWMETER CALIBRATIONS

Two NASA-supplied Technology, Inc. flowmeters were made available for use in this program. They are designated by Part Numbers S/N 004/019 and S/N 007/022. These instruments have a nominal capacity of 0.4 of a pound per minute. The signal conditioners for these two units were especially adjusted and calibrated for the range of 0.2 pounds per minute. These instruments were sent to Technology, Inc. at the beginning of this program for overhauling and recalibration and the calibration curves received are shown on figures 42 and 43 . These calibrations were again checked at NAA at the start of the program and the results reported in NAA Report TFD-65-822. Copies of this report were submitted with the Second Monthly Progress Letter. These calibrations were used during the initial portion of the program during which analyzer system development were being accomplished. Prior to the final runs of the developed analyzer (run 20 and subsequent) the flowmeters were cleaned and recalibrated. Part No. S/N 004/019 was used for the remainder of the program. This calibration was run against the North American Thermodynamics Lab No. 3 orifice plate. These calibrations were done with air, pure nitrogen, and 40-60 oxygen nitrogen mixture. A check of the flowmeters operation at 15,000 feet was also conducted. The results of these calibrations are shown on figure 44 , and were used throughout the remainder of the program. Periodic spot checks were made which indicated no shift in calibration.

Due to the necessity of integrating the output of these sensors, only a linear calibration can be used. The output was integrated by use of a planimeter on the Offner Recorder trace. Overall accuracy of better than ± 6 percent has been estimated including integration errors. This accuracy is substantially confirmed when integrated values are compared to spirometer measured samples as can be seen from the data summary sheet in figure 36 .

TECHNOLOGY INCORPORATED CURVE

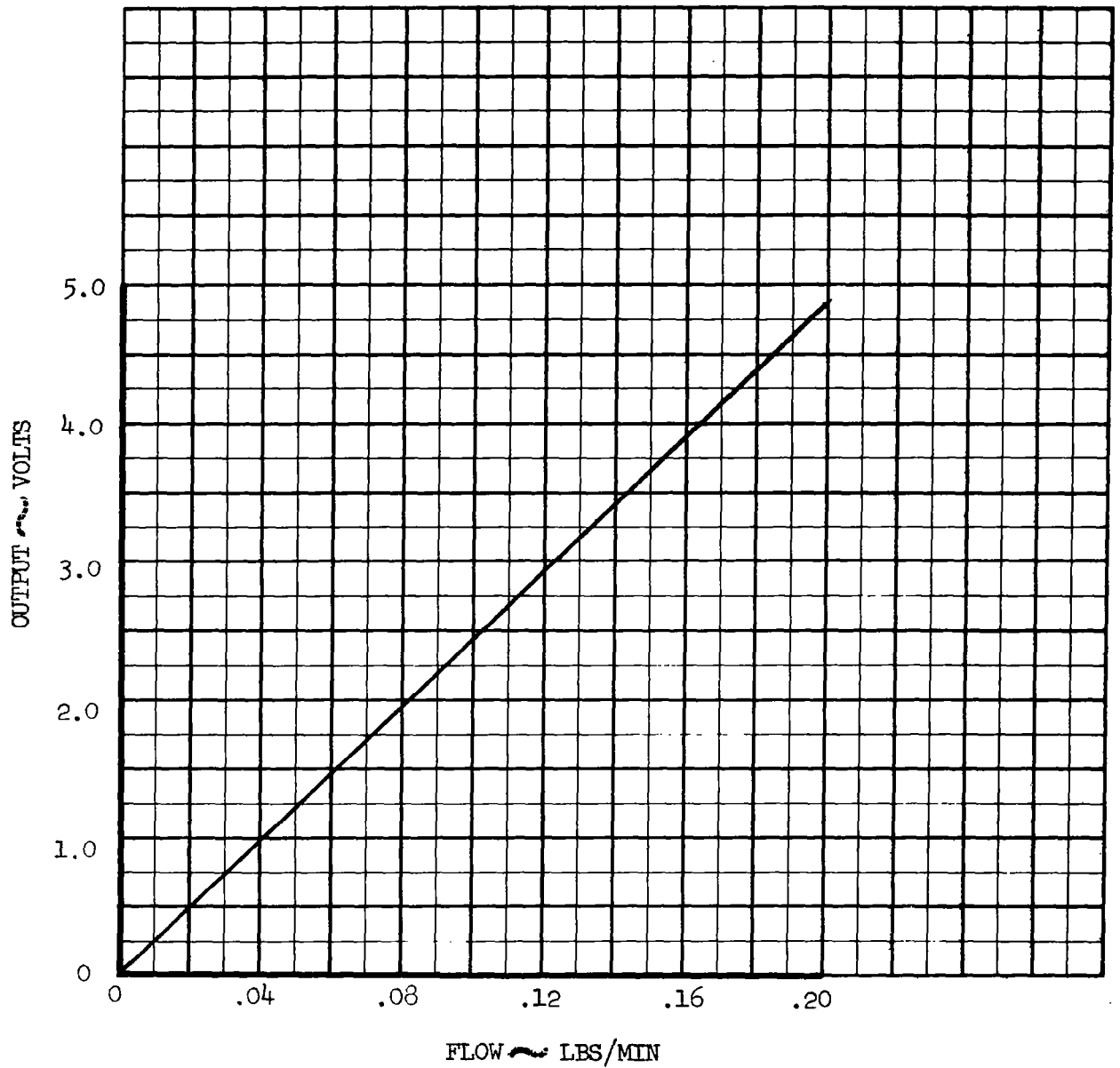


Figure 42. Calibration Data for Mass Flow Meter Serial No. 007/022.

TECHNOLOGY INCORPORATED CURVE

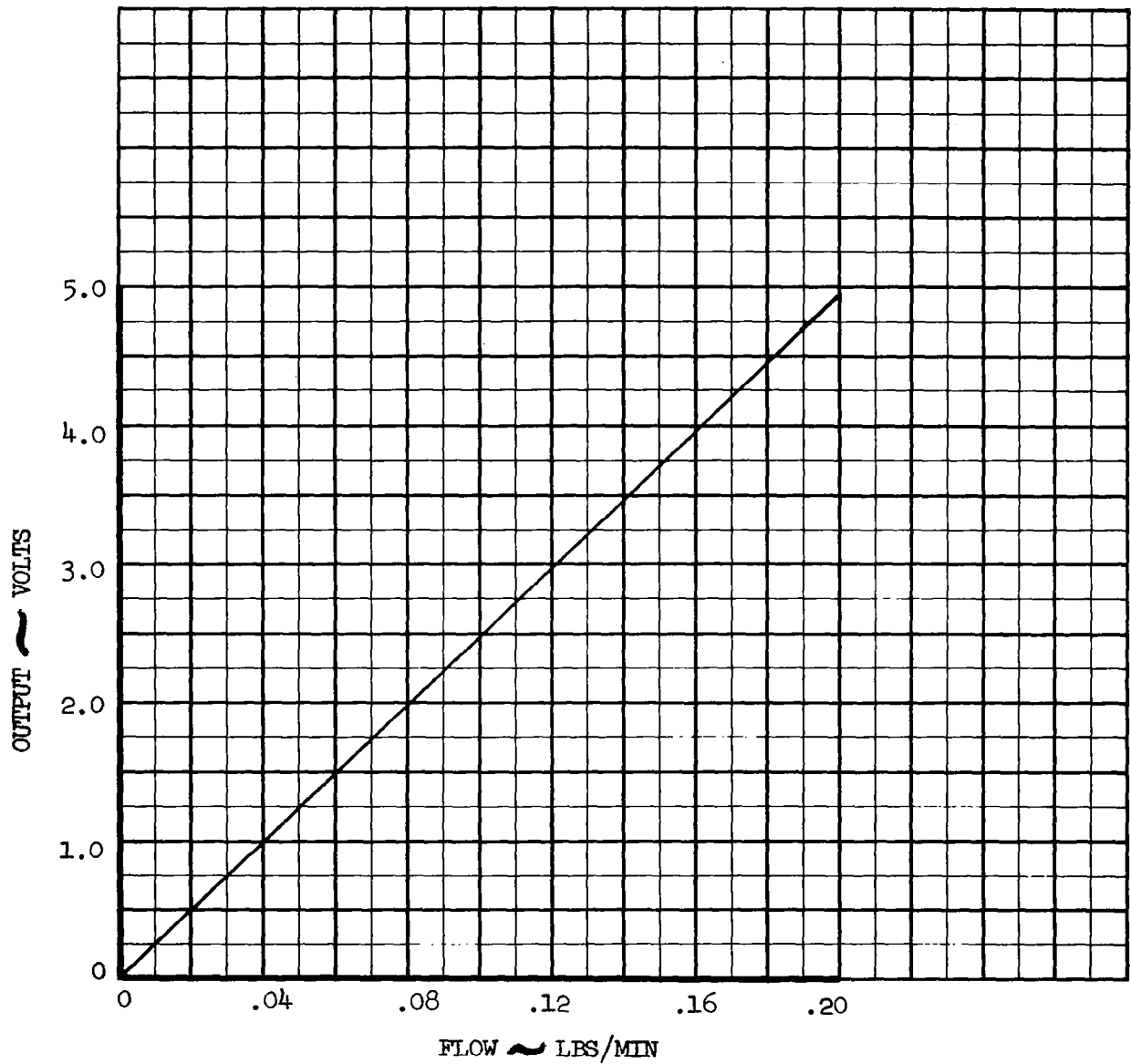


Figure 43. Calibration Data for Mass Flow Meter Serial No. 004/019.

SYM	LEGEND
○	AIR - S.L.
+	AIR - 15,000
0	40% O ₂ , 60%N ₂ , S.L.
△	N ₂ , S.L.

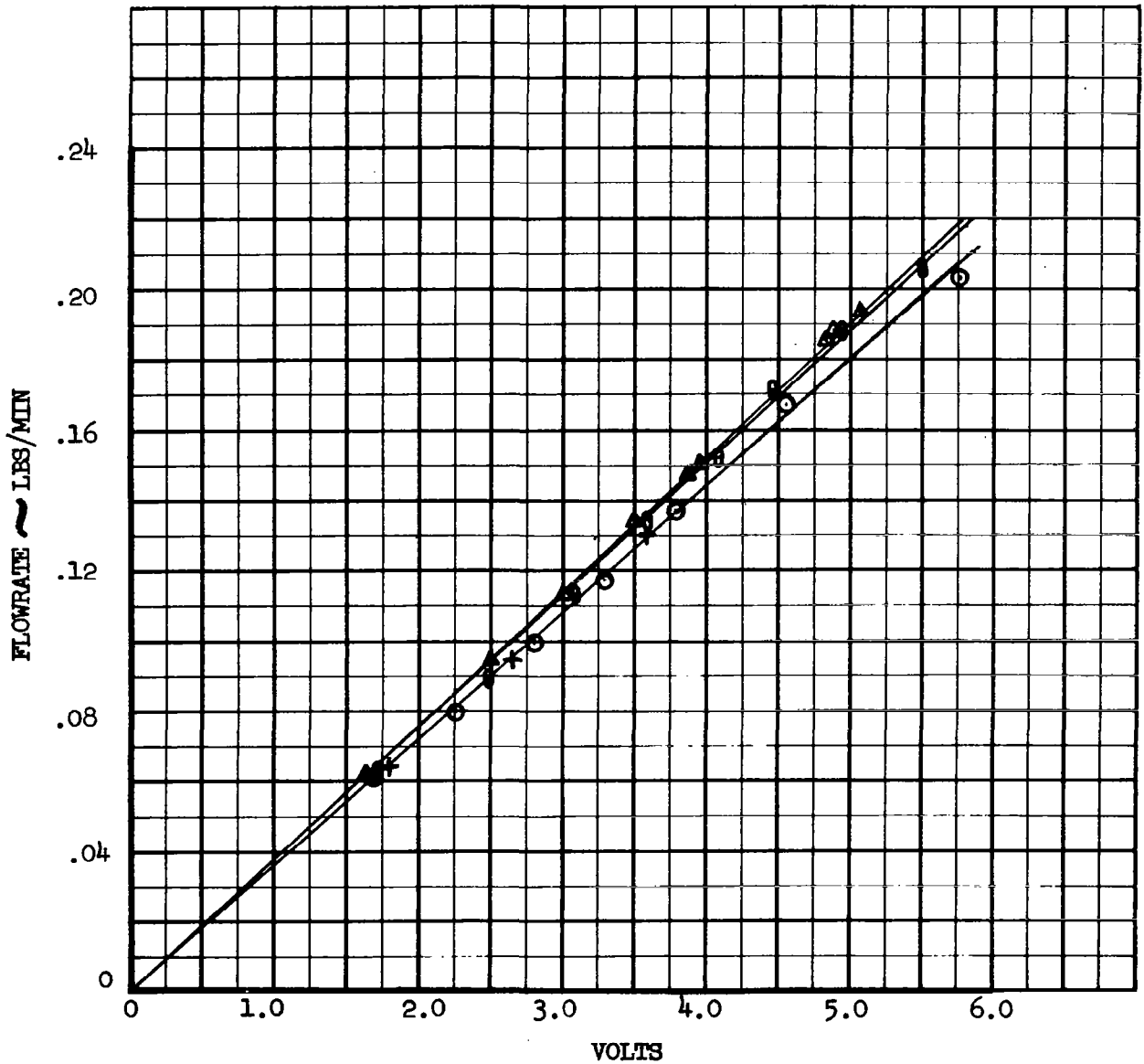


Figure 44. Flowmeter Calibration S/N 019-004.

CALIBRATION OF OXYGEN PARTIAL PRESSURE SENSOR

The oxygen partial pressure sensor and its associated electronics were designed and calibrated to provide a linear output varying from zero volts at zero partial pressure to 5 volts at 500 mm Hg partial pressure. This calibration was checked at NAA using prepared gas mixtures over a broad range. This data is shown on the left-hand side of figure 45 . More important than the absolute value of total pressure, however, is the accuracy and repeatability of a small range from an initial known value of P_{O_2} . To accomplish this calibration a meteorological balloon was filled with air and the sensor output adjusted to the known partial pressure on the Offner recorder. A small quantity of CO_2 was then introduced into the balloon. This mixture was then sampled by the analyzer and the partial pressure of CO_2 and O_2 were recorded. This procedure was repeated for various CO_2 dilutions and plotted as shown on the right-hand portion of figure 45 . The solid line shows the theoretical variation of P_{O_2} as a function of the CO_2 dilution. It will be noted that the oxygen partial pressure readings remain well within the ± 1 percent tolerance specified. This type of calibration was routinely performed from Run 20 and subsequent.

CALIBRATION OF CO_2 SENSORS

The calibrations of the interim CO_2 sensor (Beckman Monobeam unit) were accomplished by Beckman Instruments and are shown on figure 46 . This calibration was routinely spot-checked using prepared gas samples containing 0.5 percent and 3 percent CO_2 . These readings corresponded to the Beckman calibration curve and showed no tendency to shift during the period of testing. The calibration was, however, found to be sensitive to a ΔP across the sensor housing which required that the sensing unit be located in the altitude chamber for altitude tests.

The IR CO_2 sensor, finally incorporated into the unit, was calibrated by NAA at sea level pressure using sample gases of known composition and by using the relationship of P_{O_2} and P_{CO_2} as an air sample is diluted with CO_2 . This is the same technique described under "Calibration of Oxygen Partial Pressure Sensors". A shift in calibration at altitude was found by making checks with known gas mixtures. The sea level and 15,000-foot calibrations are shown in figure 47 . Time did not permit a complete

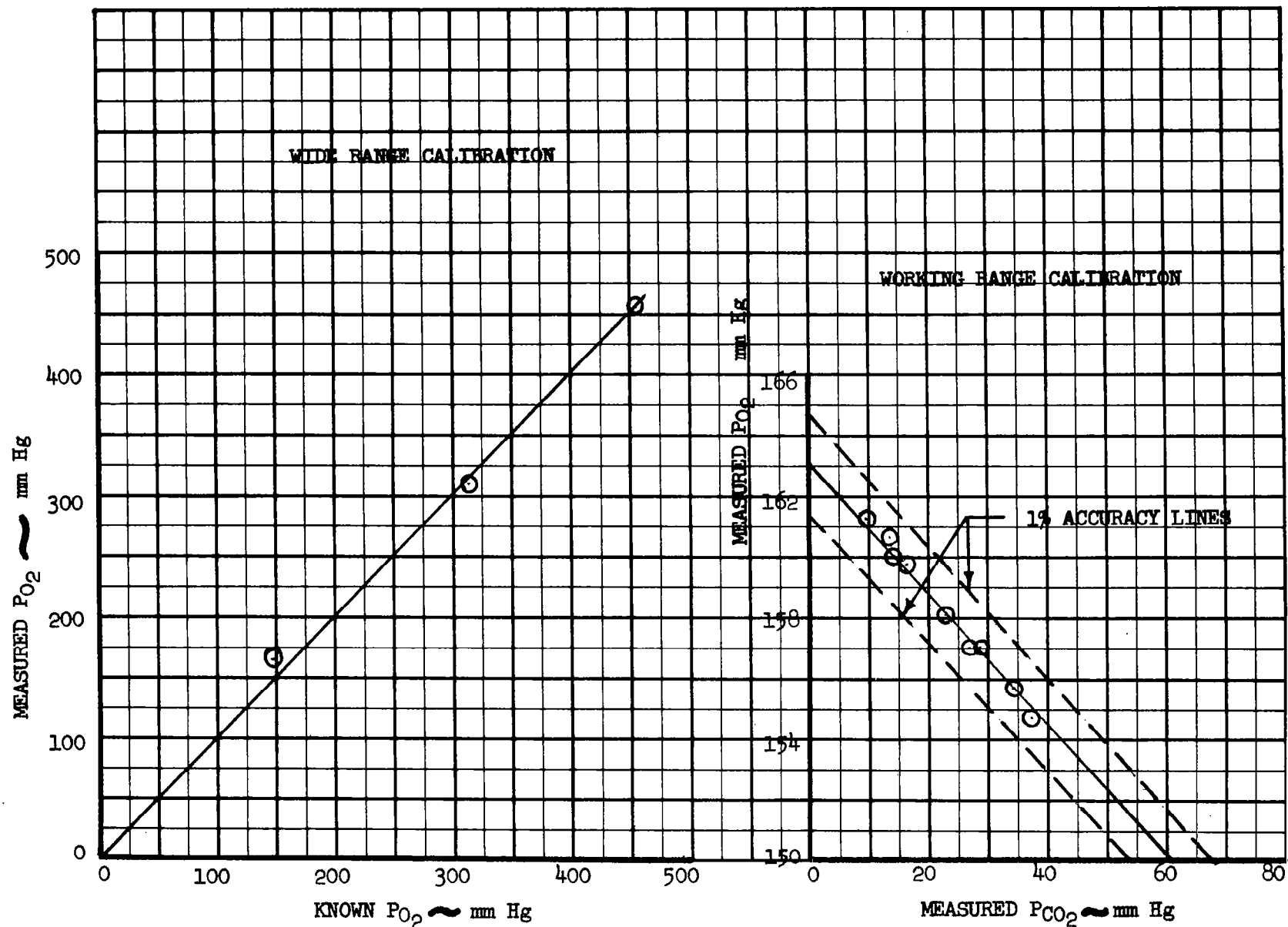


Figure 45. Respiration Analyzer P_{O_2} Sensor Calibration.

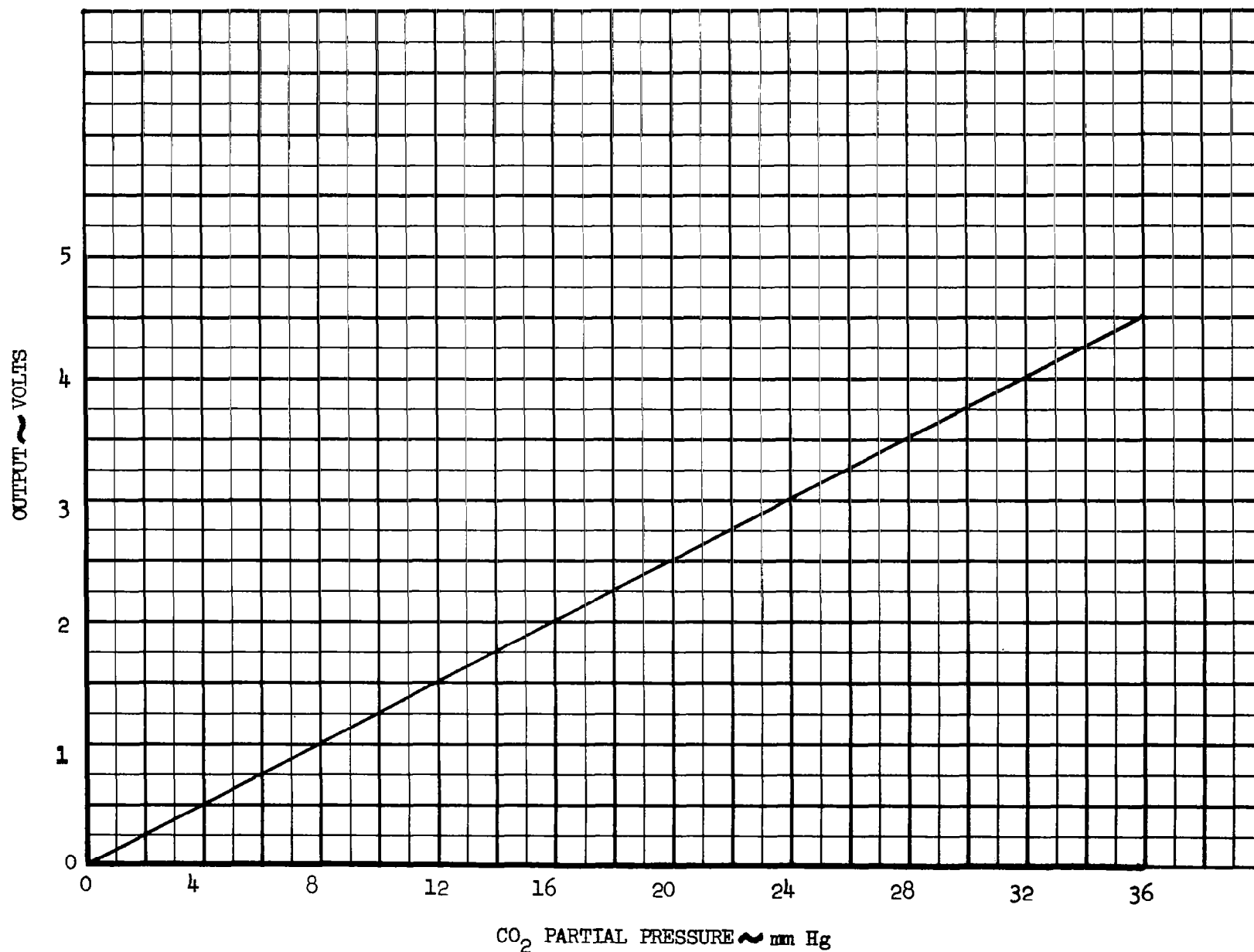


Figure 46. Respiration Analyzer Calibration CO₂ - Partial Pressure.

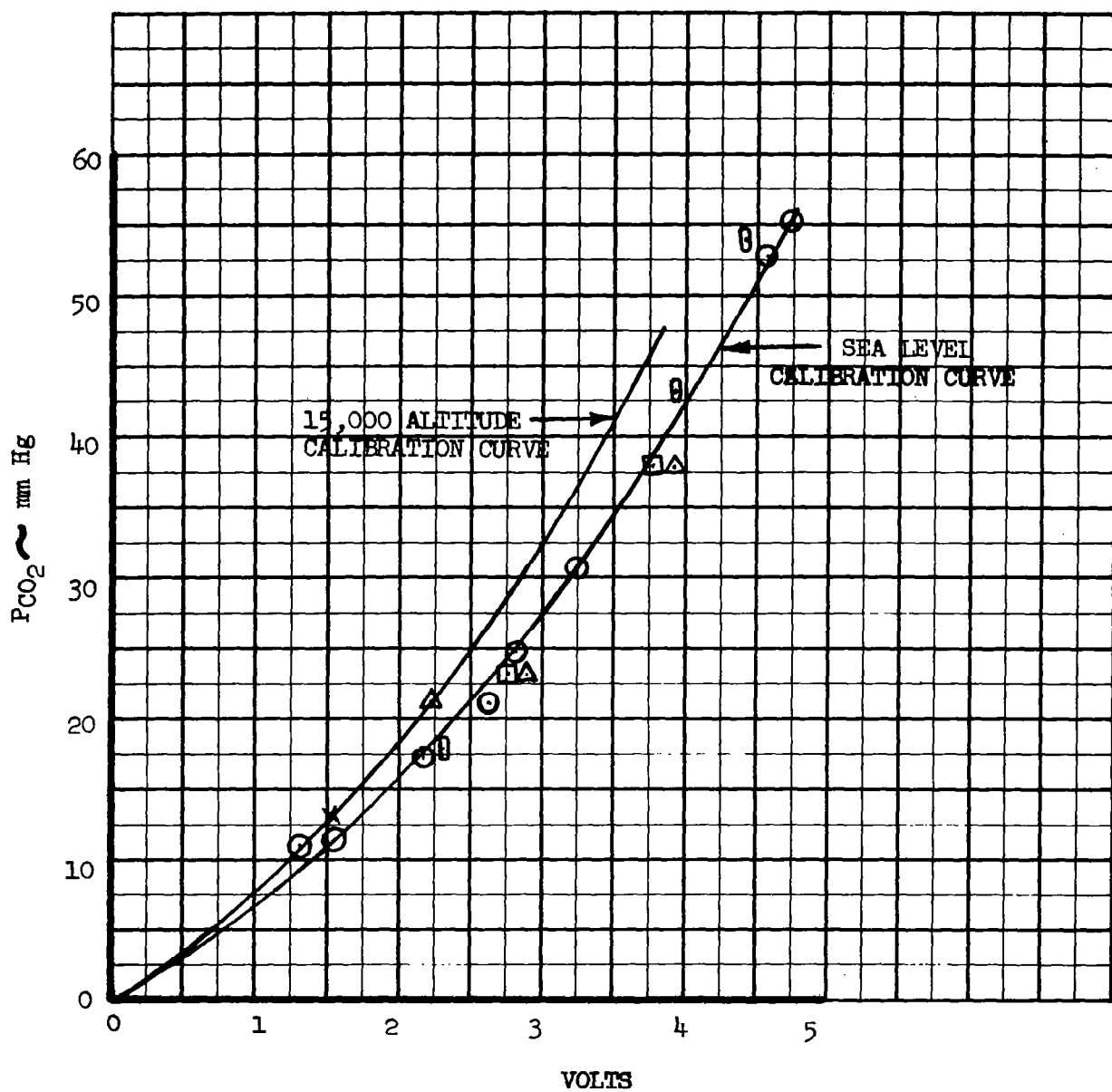


Figure 47. Calibration of IR P CO₂ Sensor.

evaluation or possible elimination of altitude sensitivity.

TOTAL PRESSURE SENSOR CALIBRATION

The total pressure sensor was calibrated by Beckman and the calibration curve is shown on figure 48 . Check points of this calibration taken during altitude runs are shown by the triangle points on the same figure.

TEMPERATURE SENSOR CALIBRATION

The temperature sensor was calibrated by Beckman and is shown on figure 49 . Since this instrument was not used, no further calibrations were obtained.

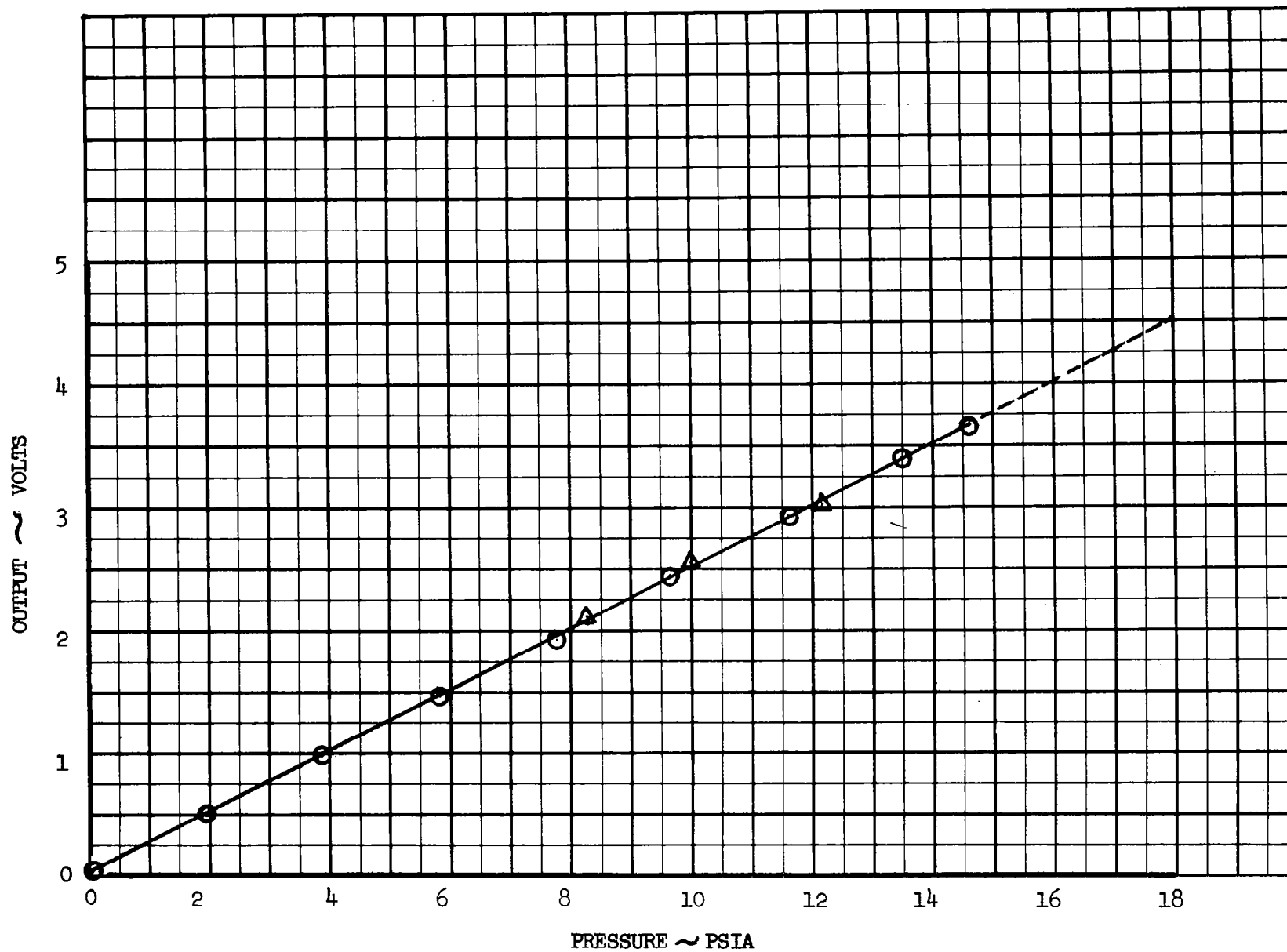


Figure 48. Respiration Analyzer Calibration Total Pressure Channel.

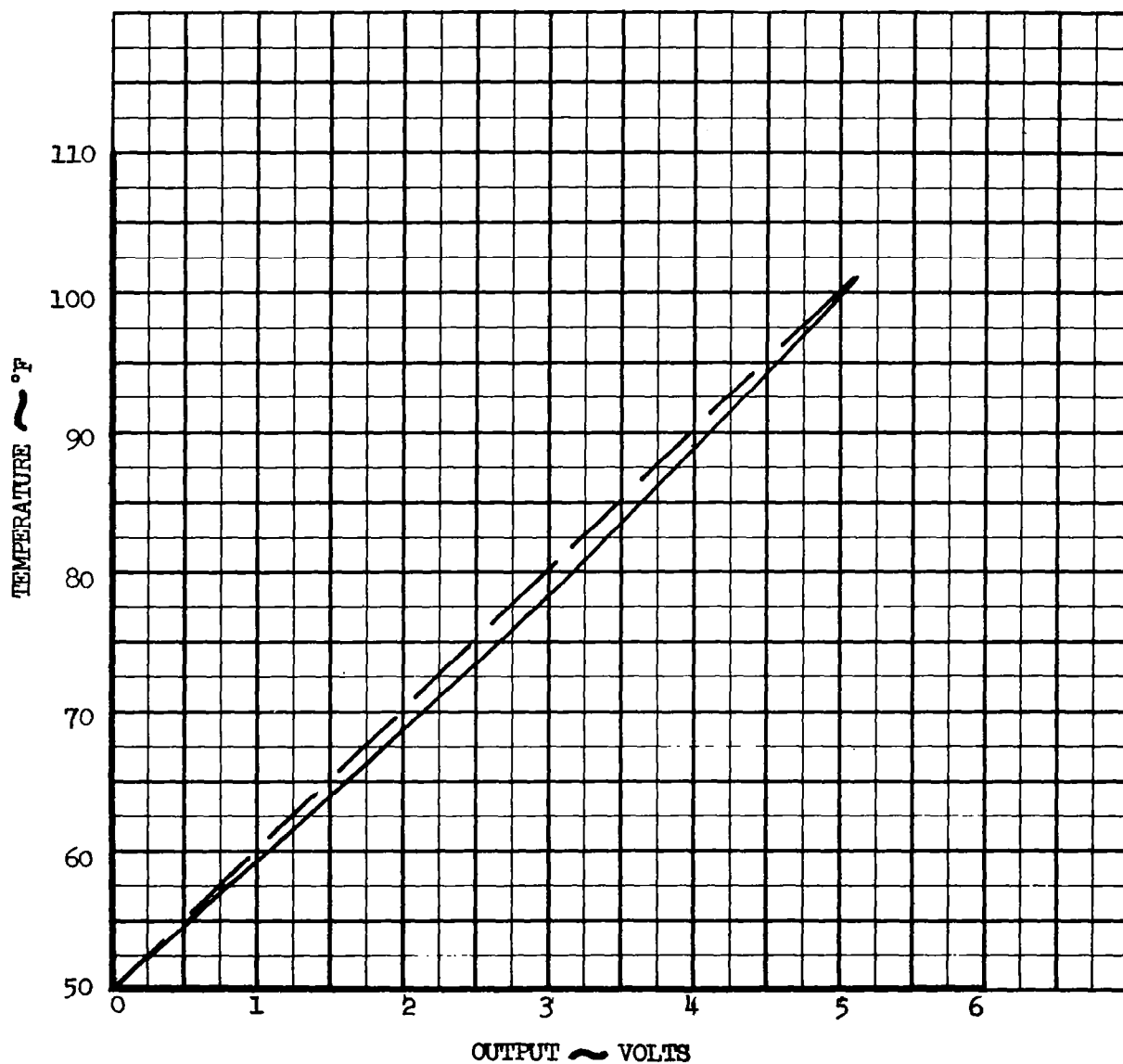


Figure 49. Respiration Analyzer Calibration Temperature.

MIXING CHAMBER DEVELOPMENT

One of the major goals of this effort was the design of small mixing chambers capable of mixing either the inspired or expired gas such that quasi-steady-state readings of the partial pressure of oxygen are obtained which are within plus or minus 1 percent of the true average value of oxygen concentration.

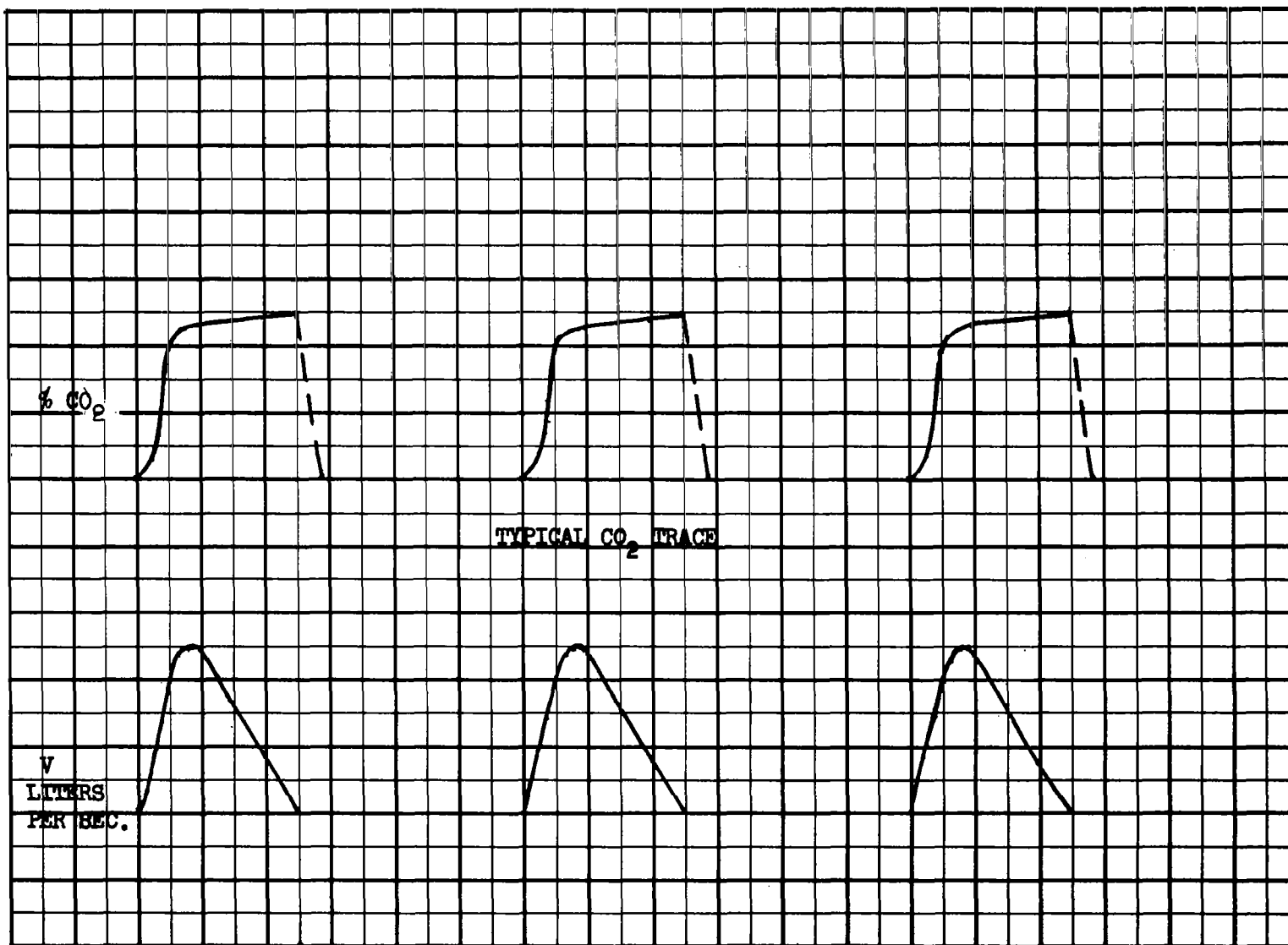
The P_{O_2} sensors utilized in the analyzer have a relatively slow response rate for measuring small and rapid fluctuation in partial pressure that might be encountered during the development of the mixing chambers. As a result it was decided to run the mixing chamber tests using CO_2 as a trace gas in determining effectiveness of the mixing. A Beckman LB-15 CO_2 analyzer was utilized as a sensing device. Before going into further details of the mixing chamber tests it may be helpful to consider the nature of the mixing problem.

Figure 50 shows a typical trace of CO_2 concentration or \dot{V} at a point in a tube through which a man is exhaling. Since we are concerned with the mass of O_2 consumed, or the mass of CO_2 produced rather than a time average of percent gas composition, it is essential that the percent concentration be averaged with respect to \dot{V} rather than with respect to time. In other words, if we are to sample the expired breath of a man as it flows past a point in a tube it would be essential to integrate the percent concentration at the sampling point with respect to \dot{V} according to equation 14 rather than taking the time average of the

$$\frac{\int_0^t \% CO_2 \dot{V} dt}{\int_0^t \dot{V} dt} \quad (14)$$

percent concentration according to equation

$$\frac{\int_0^t \% CO_2 dt}{\int_0^t dt} \quad (15)$$



TYPICAL RESPIRATORY VOLUME FLOW RATE TRACE

Figure 50. Typical Traces of CO₂ Concentration and V.

Since it is undesirable to simultaneously measure \dot{V} and percent concentration and perform an integration according to equation 15, a mixing chamber may be used to reduce variations in percent concentration to such a low value that it can be considered a constant resulting in the following equation 16.

$$\frac{\%CO_2 \int_0^t \dot{V} dt}{\int_0^t \dot{V} dt} = \%CO_2 \quad (16)$$

From a practical standpoint, however, it might be difficult to mix to a sufficient degree that the percent concentration can be considered an absolute constant. It can be seen, however, that even if we evaluated the integral (15) we would get some approximation of the true concentration and the error would be a function of the time relations between \dot{V} and percent concentration. Take for example, one cycle of the approximate traces shown in figure 50 and evaluate both integrals. This integration is shown graphically in figure 51. Here we note that the averaged value gives a concentration of carbon dioxide of 3.98 percent, whereas the integration with respect to \dot{V} gives a value of 4.26 percent. We might argue then that if a mixing process could be developed to accomplish a major smoothing of the percent concentration versus time curve, that a further time averaging of the smoothed curve would provide the desired accuracy. This reasoning gave rise to a two-stage mixer as a possible approach to minimizing size and complexity of the mixing chamber. In this concept a small sample is withdrawn from the discharge of a reasonably effective mixing chamber where some small ripple might be present. The sample is then further mixed in a small packed bed to remove this ripple. Sample data for both single and two-stage mixers are shown in the following test results.

A schematic of a test setup is shown on figure 52. A breathing machine is used to cause pulsatile flow through the mixing chamber. Metered quantities of CO_2 are introduced in either a steady-state manner or intermittently coinciding with the expiration time of the breathing machine. A sample is withdrawn from the mixing chamber and passed through the LB-15 analyzer

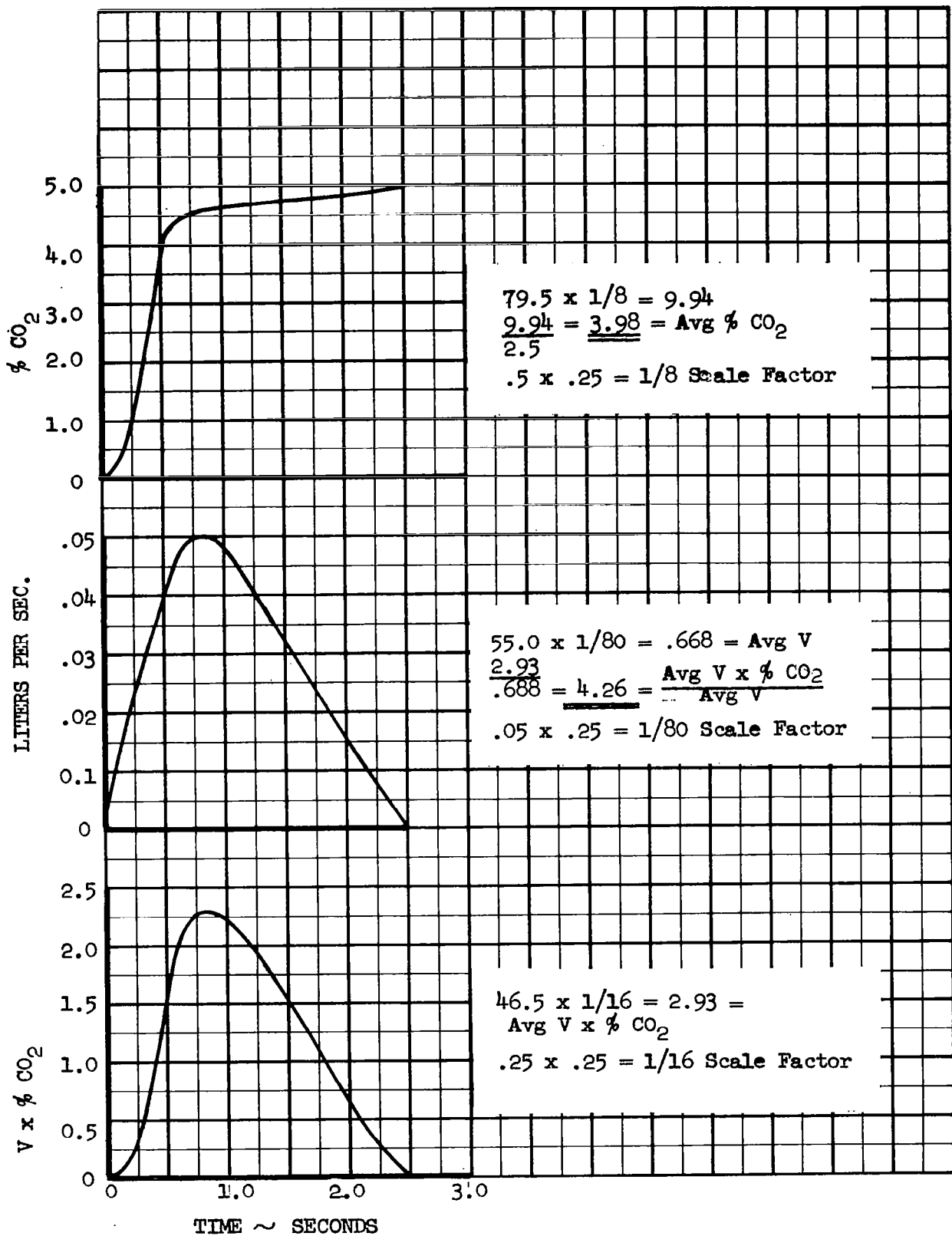


Figure 51. Typical Integration of A Breathing Cycle.

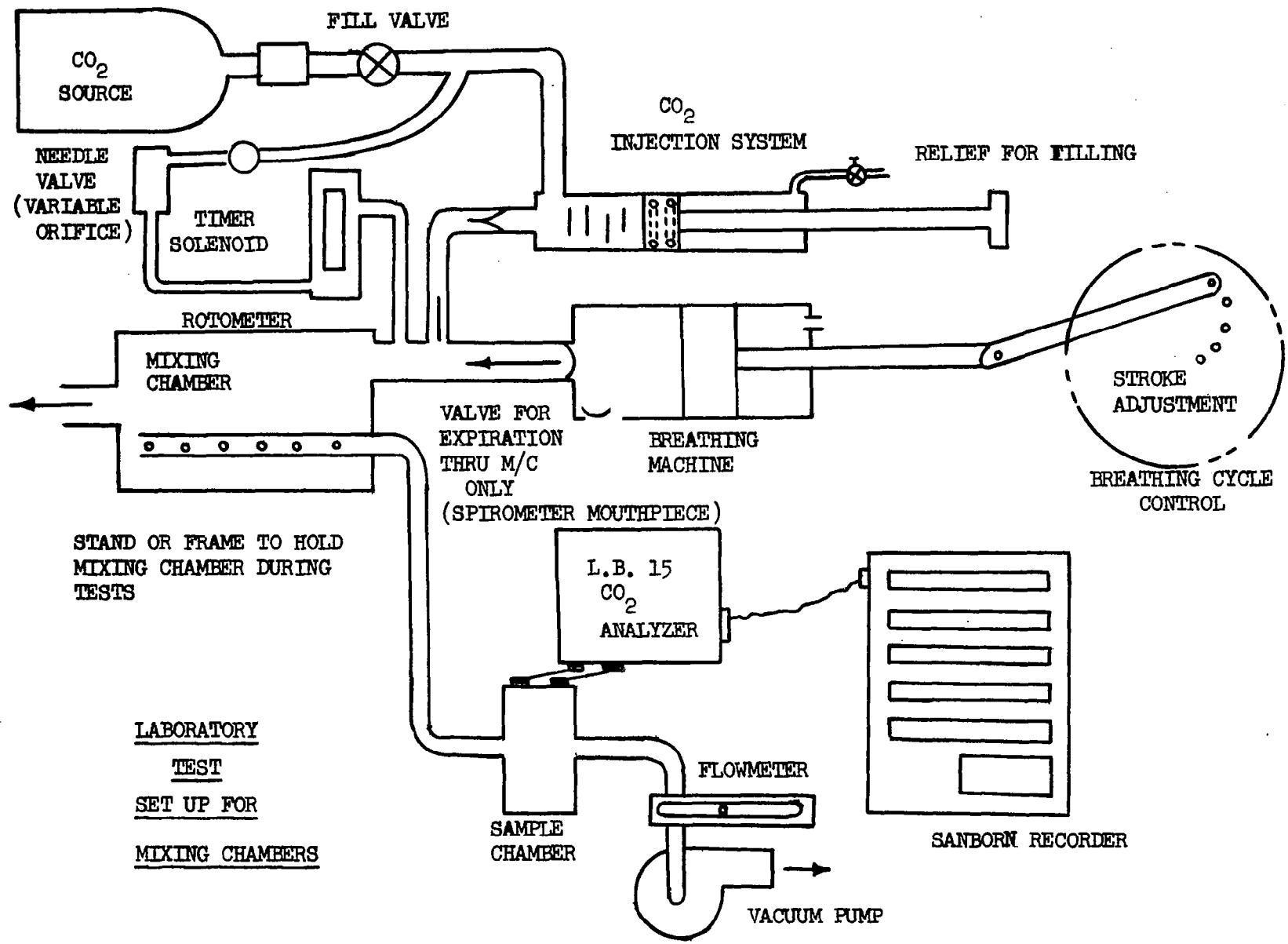


Figure 52. Schematic of Mixing Chamber Laboratory Test Set-up.

by means of a vacuum pump. The output of the LB-15 analyzer is recorded on the Sanborne recorder. The variations in concentration produced by this simulation are actually more severe than those experienced during an actual breathing cycle.

Three basic test configurations were used: A straight plastic tube with a concentric piccolo-type sample tube, a mixing chamber shown on figure 53, and a combination of a mixing chamber followed by a straight tube with a concentric sample tube. Data are taken with and without a pebble bed in the sample line, and with both steady-state and pulsatile inputs of CO_2 .

Figure 54a shows the results using the straight tube with the concentric sample tube for a steady-state CO_2 input. The concentration of CO_2 computed on the basis of the breathing machine output and CO_2 injection rate is 6 percent. Metering and control of the CO_2 injection is estimated within ± 5 percent for the steady-state injection with slightly greater variation possible with pulsatile injection. Thus, the actual percent concentration could be expected to be between about 5.7 and 6.3 percent. The data trace shows a strong sinusoidal variation between 4.3 and 5.7 percent. Figure 54b shows the same configuration with the same concentration of CO_2 but with the CO_2 introduced only during the exhalation cycle of the breathing machine. As would be expected, the variation was somewhat smaller but still quite appreciable and the value less than the actual CO_2 concentration. Figures 55a and 55b show the same configuration and conditions but with the pebble bed in the sample line to the analyzer. Here we see the pebble bed has smoothed the data nicely but the reading is considerably lower than the actual concentration.

Figures 56a and 56b show the performance obtained under the same conditions with a mixing chamber. The level of the data are within the accuracy of the CO_2 's injection measurements and only a small ripple is present. Figures 57a and 57b show the same setup with the addition of the pebble bed in the sampling line. Its effectiveness in removing the ripple is apparent.

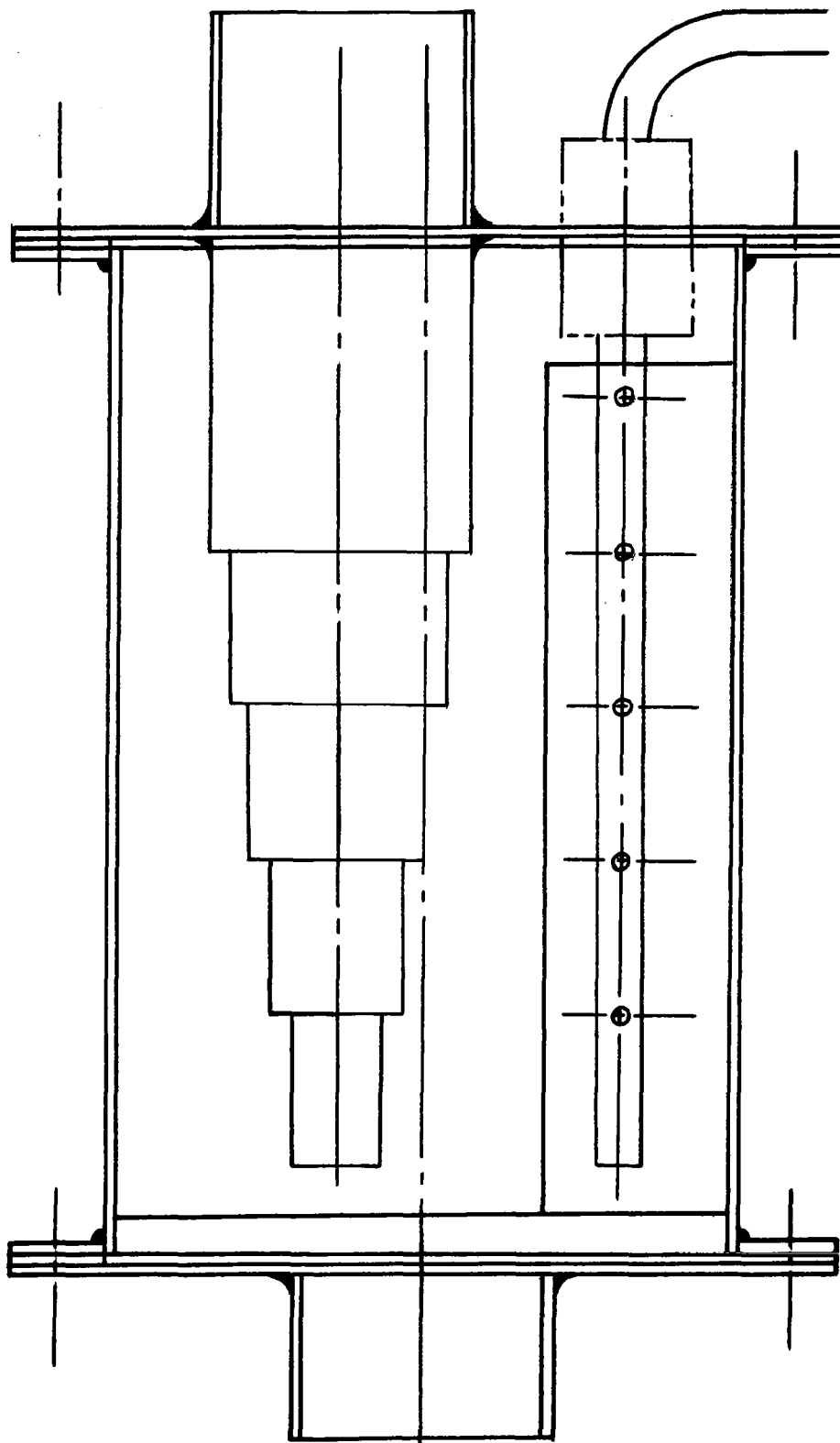


Figure 53. Expiratory Mixing Chamber.

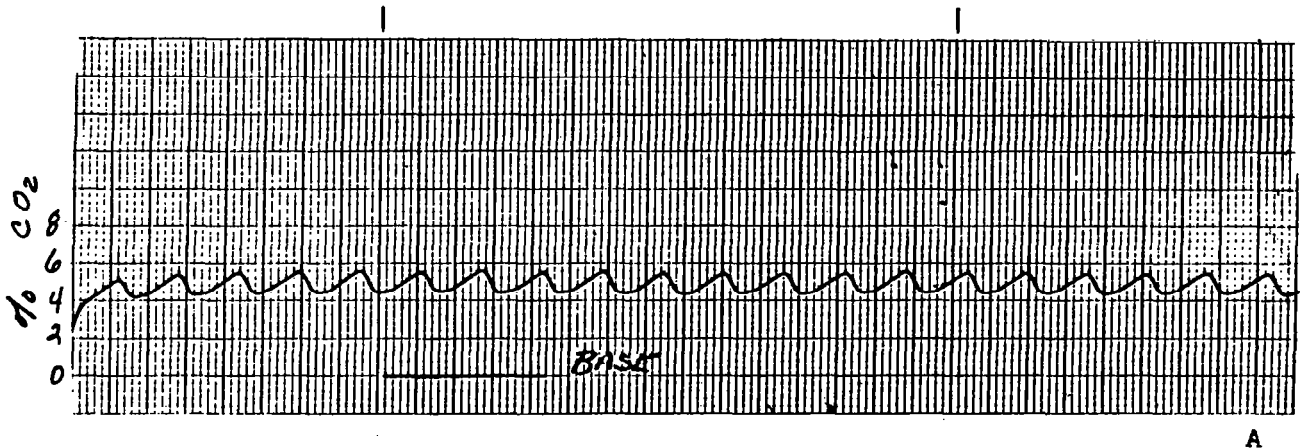
Figures 58a and 58b show the performance of a mixing chamber followed by a straight tube. Sampling is accomplished by a "piccolo" tube concentric with the straight tube. This configuration was checked to determine desirability of sampling at a point in the system downstream of the mixing chamber. This configuration displays somewhat less ripple and when tested with a pebble bed (figures 59a and 59b) produces a very smooth trace.

The configuration selected for test in the analyzer was the mixing chamber followed by the pebble bed mixer. Sampling downstream of the mixing chamber was not selected since it might not be most amenable to a flight installation and did not appear to offer any major improvement. Such an installation would be recommended, however, if convenient. The "pebble bed" mixing in the actual analyzer is accomplished by the heat sink heat exchanger.

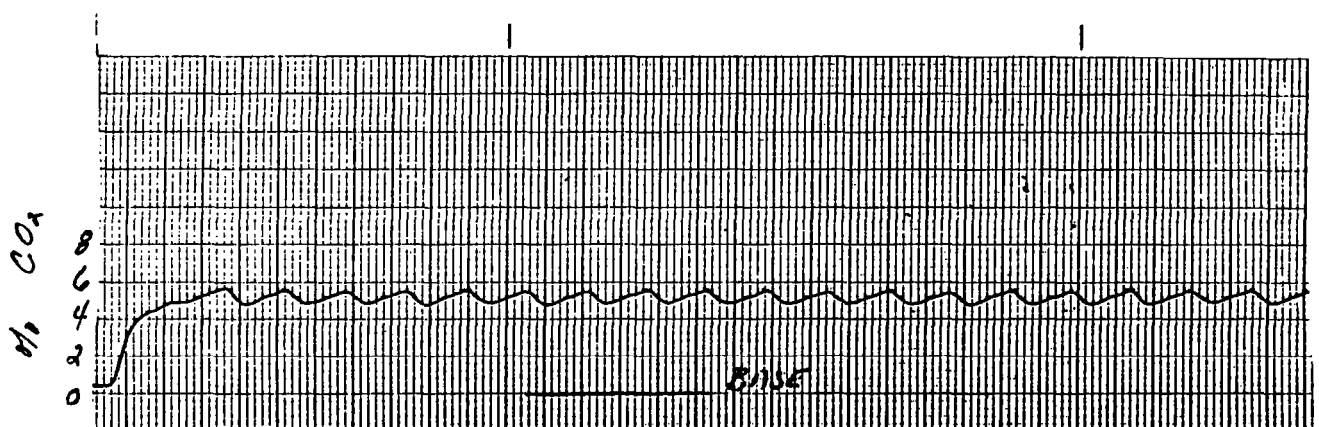
Further proof of the effectiveness of the mixing chamber is found in the actual testing of the analyzer system as discussed previously in this report.

Figure 54

MIXING CHAMBER TEST		DESCRIPTION OF CONFIGURATION
BREATHS PER MINUTE	15	No mixing chamber-
VOLUME PER BREATH	400CC	Straight tube with sample tube
CO ₂ RATE		in center (concentric). No
STEADY-STATE	300 CC/MIN	pebble bed in sample line
INPUT CO ₂	= 6.0%	to analyzer



		DESCRIPTION OF CONFIGURATION
BREATHS PER MINUTE	15	No mixing chamber-
VOLUME PER BREATH	400CC	Straight tube with sample
CO ₂ RATE		tube concentric in center of
PULSATILE	600CC/MIN	tube. No pebble bed in sample
INPUT CO ₂	= 6.0%	line to LB-15 analyzer

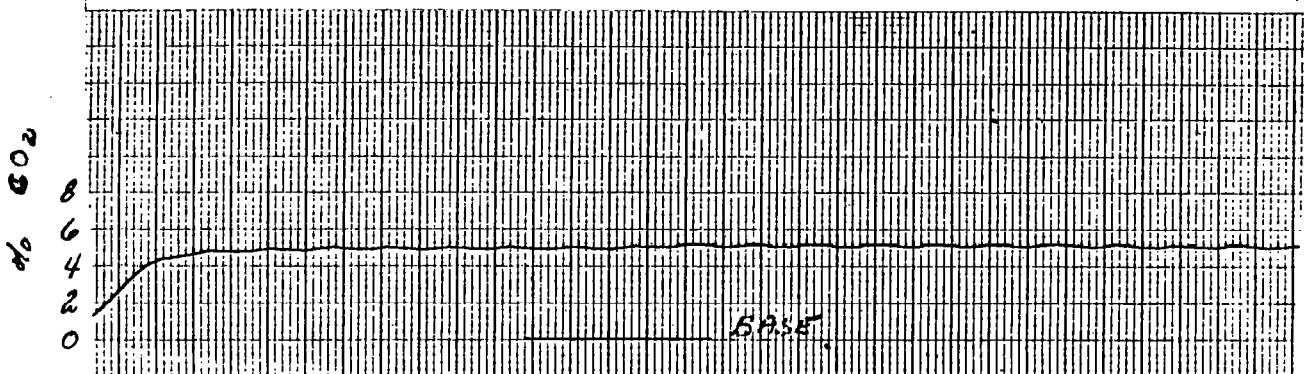


MIXING CHAMBER TEST

Figure 55

BREATHS PER MINUTE 15
 VOLUME PER BREATH 400CC
 CO₂ RATE
 STEADY-STATE 300 CC/MIN
 CO₂ = 6.0 %

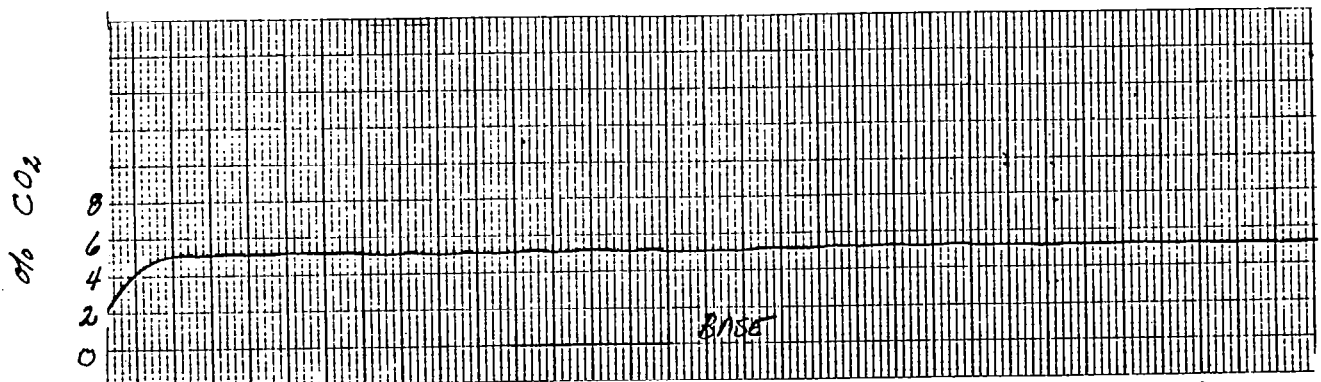
DESCRIPTION OF CONFIGURATION
 No mixing chamber-
 Straight tube with concentric
 sample tube in center. Also
 pebble bed in sample line to
 LB-15 analyzer.



A

BREATHS PER MINUTE 15
 VOLUME PER BREATH 400 CC
 CO₂ RATE
 PULSATILE 600 CC/MIN
 CO₂ = 6.0%

DESCRIPTION OF CONFIGURATION
 No mixing chamber-
 Straight tube with sample
 tube concentric in center of
 tube. Pebble bed is in
 sample line to analyzer



B

Figure 56

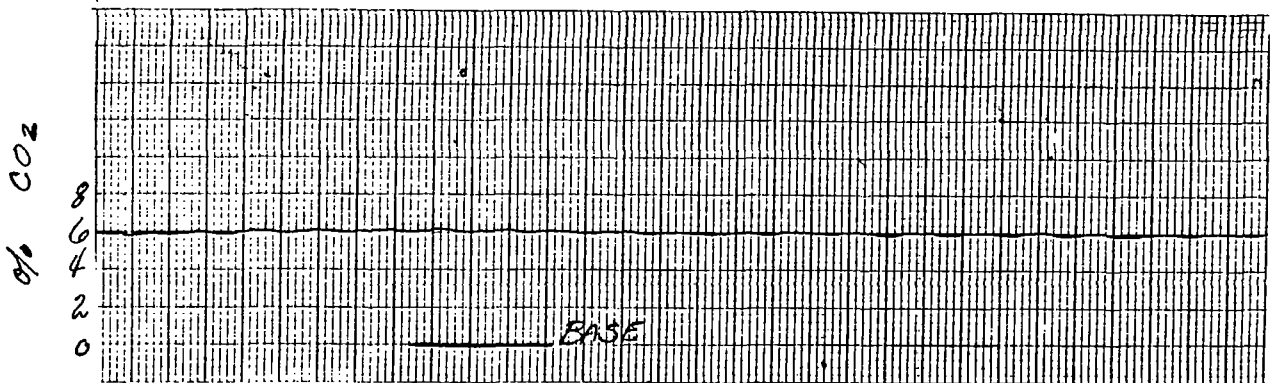
MIXING CHAMBER TEST

BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400CC

DESCRIPTION OF CONFIGURATION
Mixing chamber without pebble
bed in sample line

STEADY-STATE 300 CC/MIN
INPUT CO₂ = 6.0%



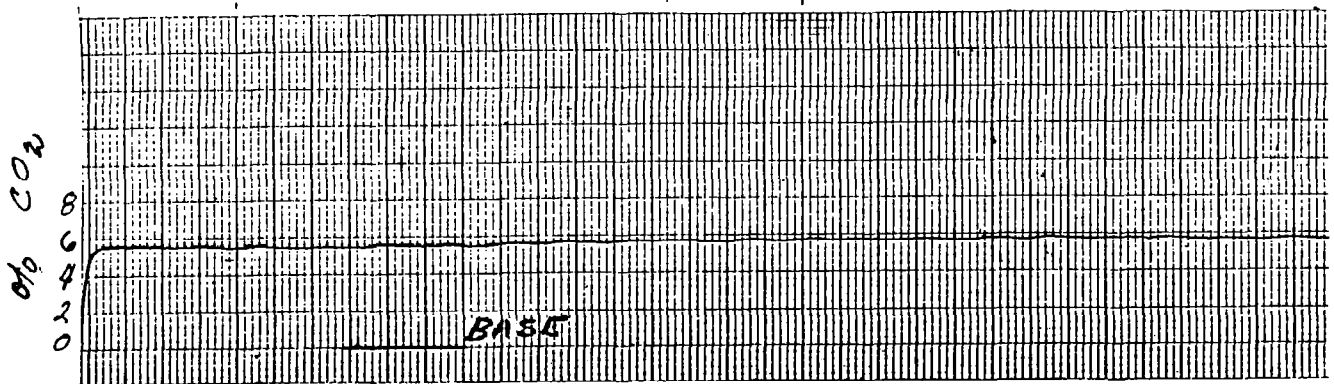
A

BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400CC

DESCRIPTION OF CONFIGURATION
Mixing chamber without
pebble bed in sample line

PULSATILE 600CC/MIN
INPUT CO₂ = 6.0%



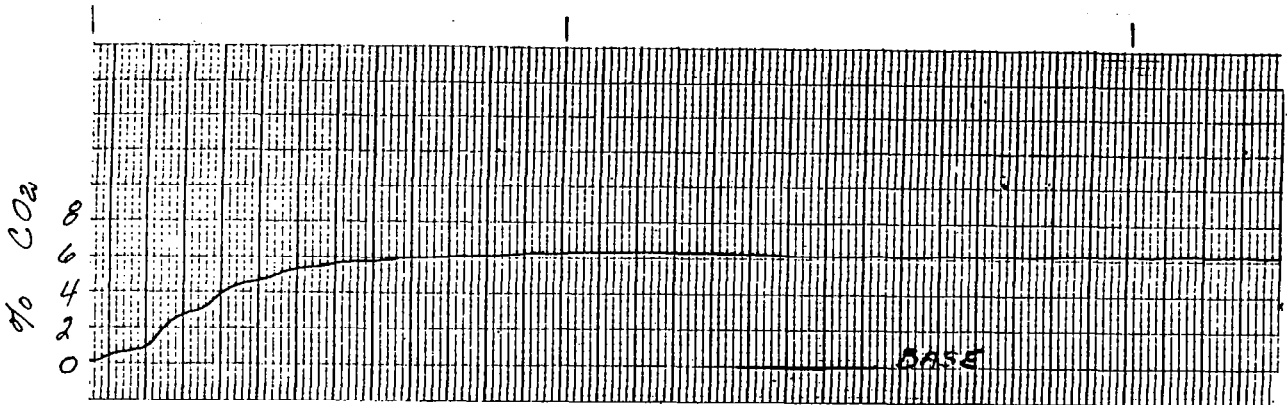
B

Figure 57

MIXING CHAMBER TEST

BREATHS PER MINUTE 15
 VOLUME PER BREATH 400 CC
 CO₂ RATE
 STEADY-STATE 300 CC/MIN
 CO₂ = 6.0%

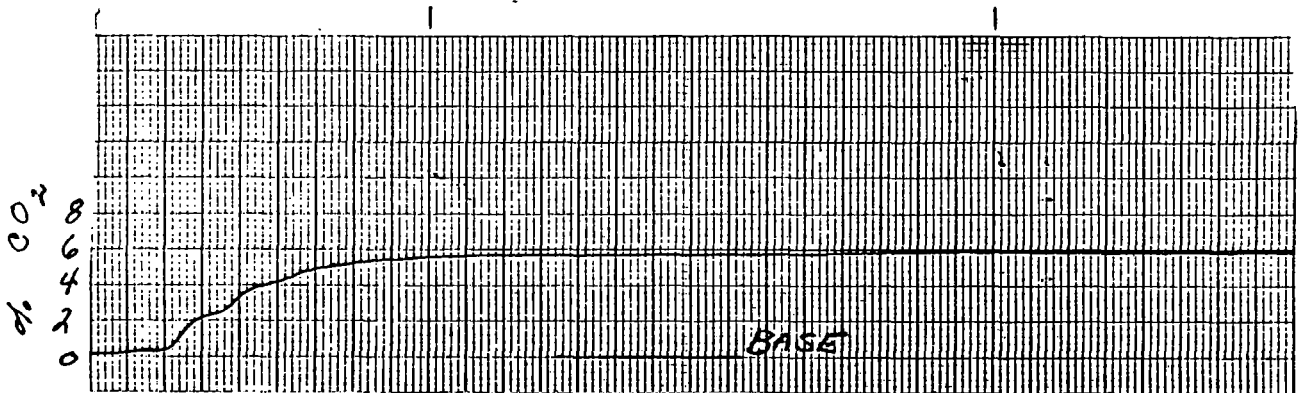
DESCRIPTION OF CONFIGURATION
 Mixing chamber with pebble
 bed in sampling line



A

BREATHS PER MINUTE 15
 VOLUME PER BREATH 400CC
 CO₂ RATE
 PULSATILE 600 CC/MIN
 CO₂ = 6.0 %

DESCRIPTION OF CONFIGURATION
 Mixing chamber with pebble
 bed in sampling line.



B

Figure 58

MIXING CHAMBER TEST

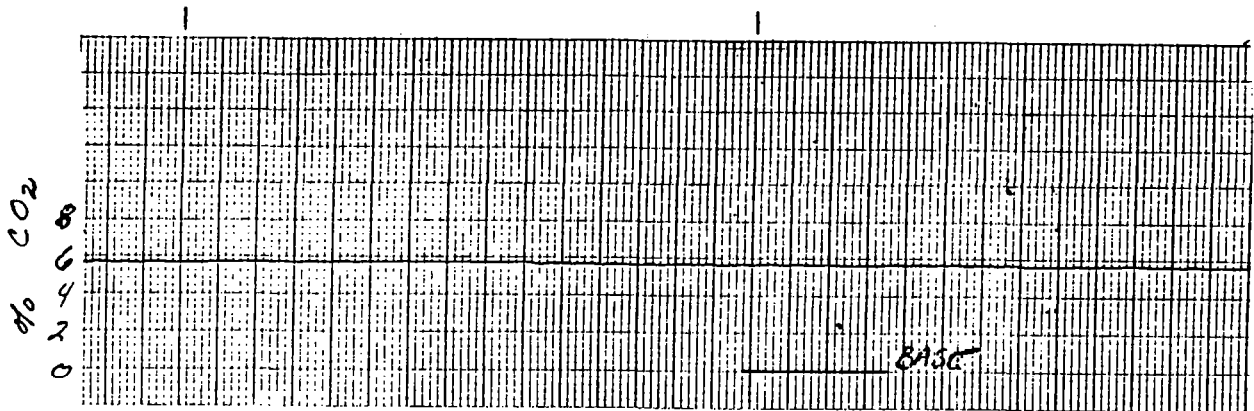
BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400 CC

STEADY-STATE
CO₂ = 6.0 %

300 CC/MIN

DESCRIPTION OF CONFIGURATION
Mixing chamber and straight
tube with concentric sample
tube. No pebble bed in
sample line to LB-15 analyzer.



A

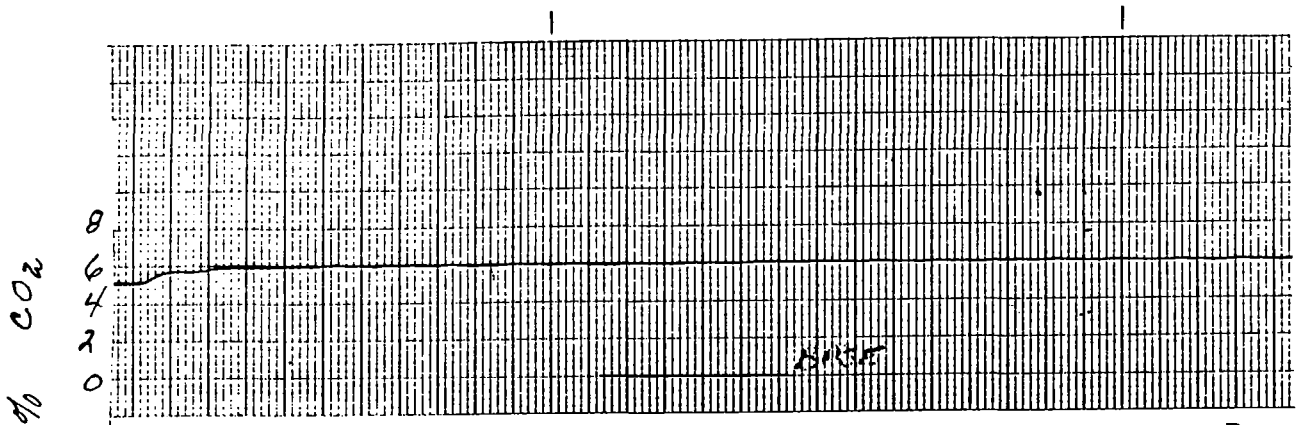
BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400 CC

PULSATILE
CO₂ = 6.0%

600 CC/MIN

DESCRIPTION OF CONFIGURATION
Mixing chamber and straight
tube with concentric
sample tube. No pebble bed
in sample line to LB-15
analyzer



B

Figure 59

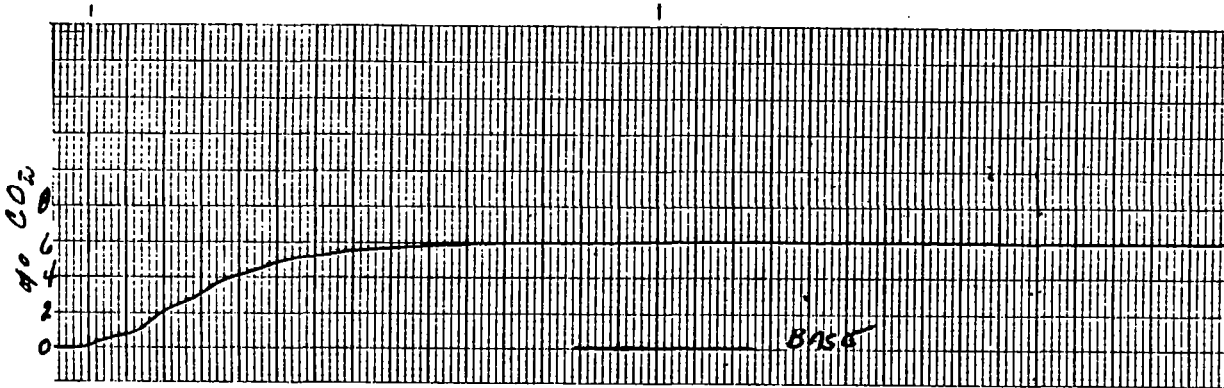
MIXING CHAMBER TEST

BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400 CC

DESCRIPTION OF CONFIGURATION
Mixing chamber and straight
tube with concentric sample
tube. A pebble bed is in the
sample line to the LB-15
analyzer

STEADY-STATE 300 CC/MIN
INPUT CO₂ = 6.0%



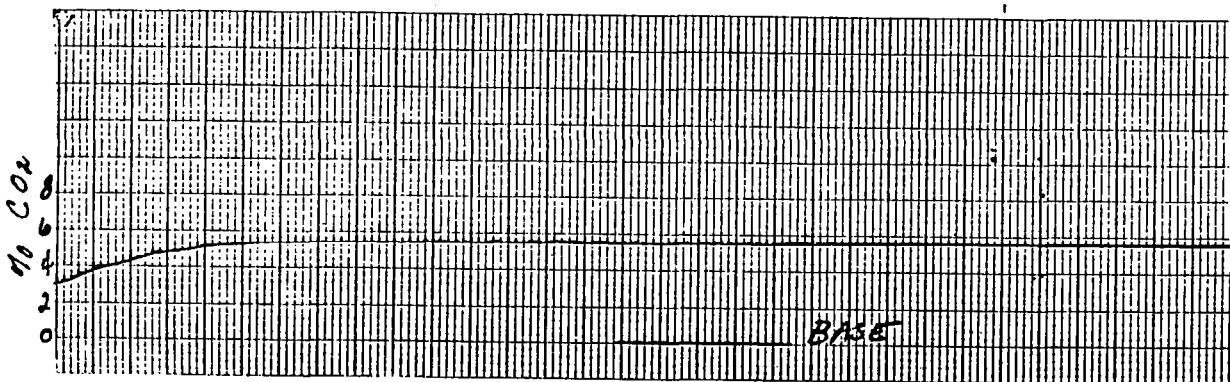
A

BREATHS PER MINUTE
VOLUME PER BREATH
CO₂ RATE

15
400 CC
600 CC/MIN

DESCRIPTION OF CONFIGURATION
Mixing chamber and straight
tube with concentric sample
tube. A pebble bed is in the
sample line to the LB-15
analyzer.

PULSATILE
INPUT CO₂ = 6.0%



B

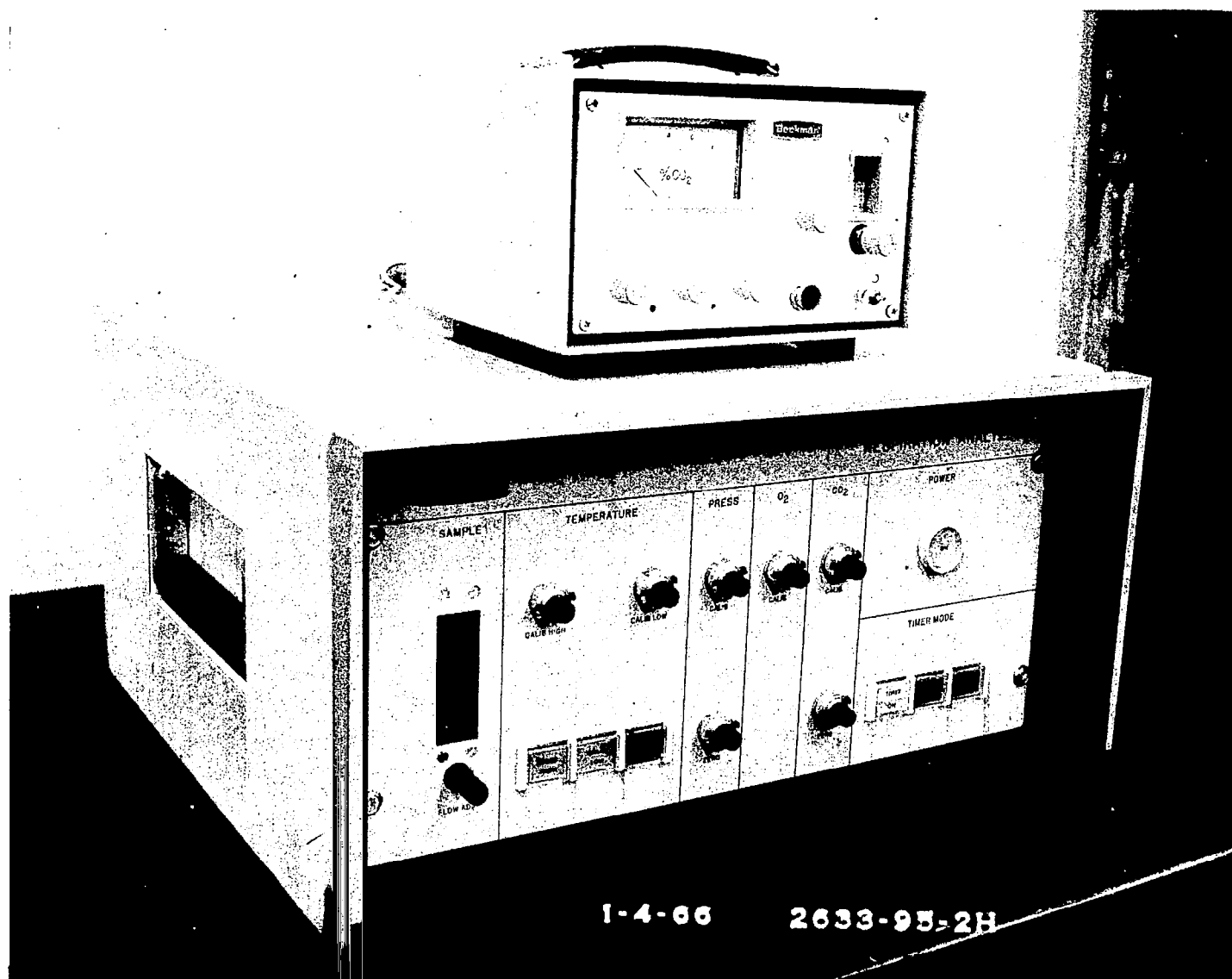
CONCLUSIONS AND RECOMMENDATIONS

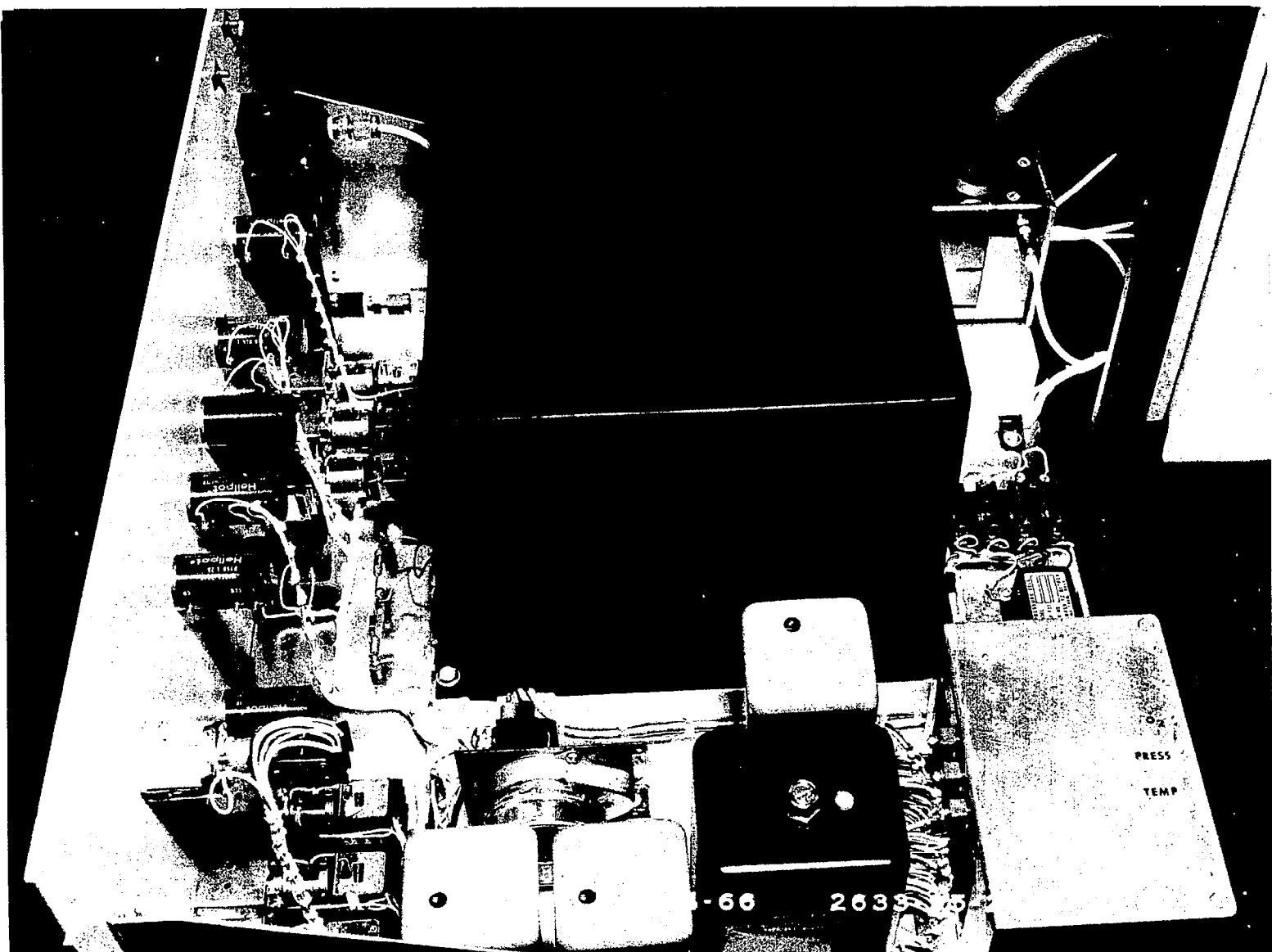
The test program conducted under this contract has proved the feasibility of measuring man's respiration products and oxygen consumption within ± 10 percent using equipment compatible with aerospace crew compartments and associated environments. It has specifically demonstrated the effectiveness of single sensors to measure both inspired and expired gases within ± 1 percent, and of small mixing chambers to remove the breath-by-breath fluctuation of gas composition to be compatible with these accuracies. It has demonstrated these abilities over an altitude range from sea level to 15,000 feet.

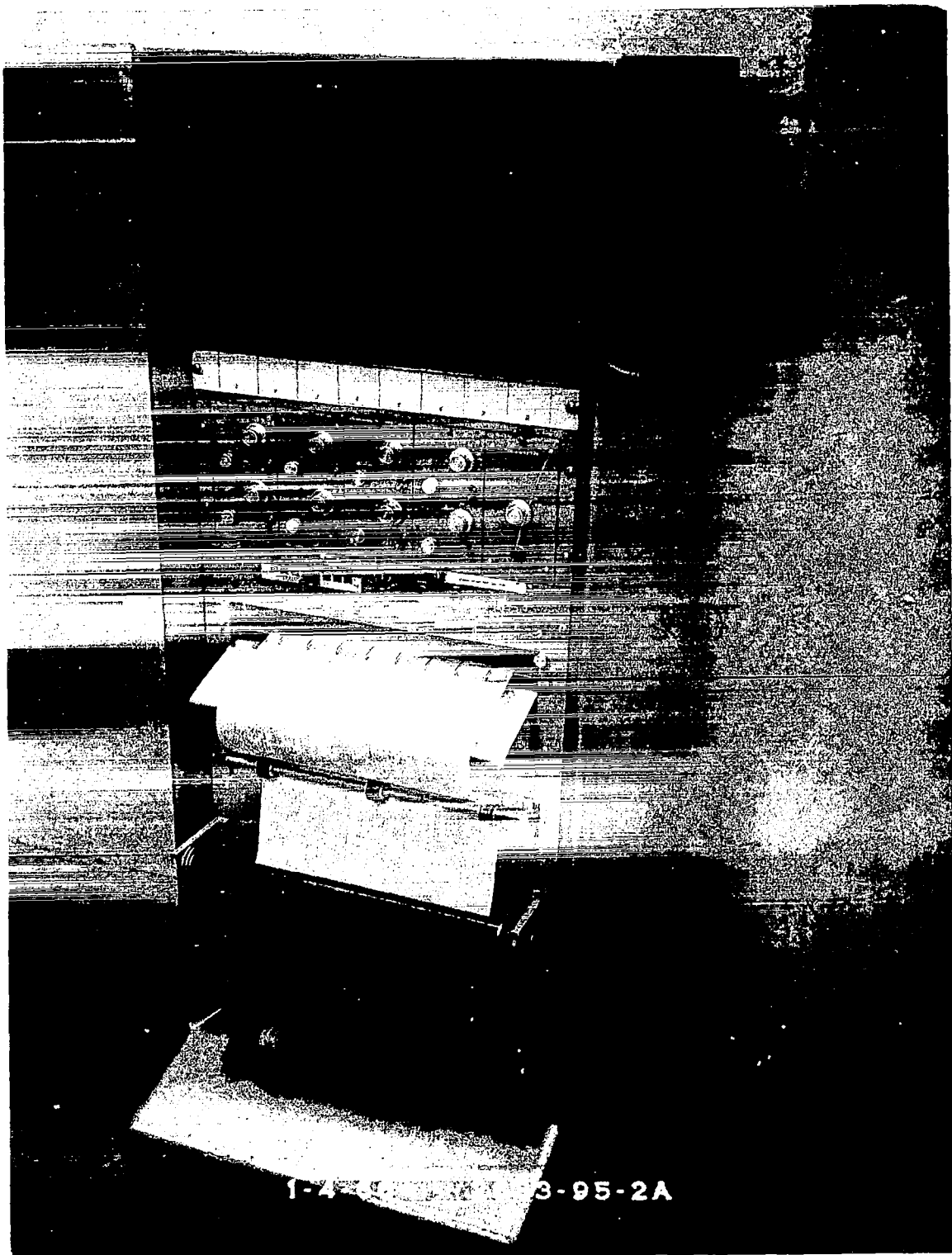
The success of this work warrants further effort geared to produce flight-rated hardware, select appropriate airborne recording devices, and develop mechanized data reduction methods. Its usefulness in systems for determining cardiac output should also be investigated.

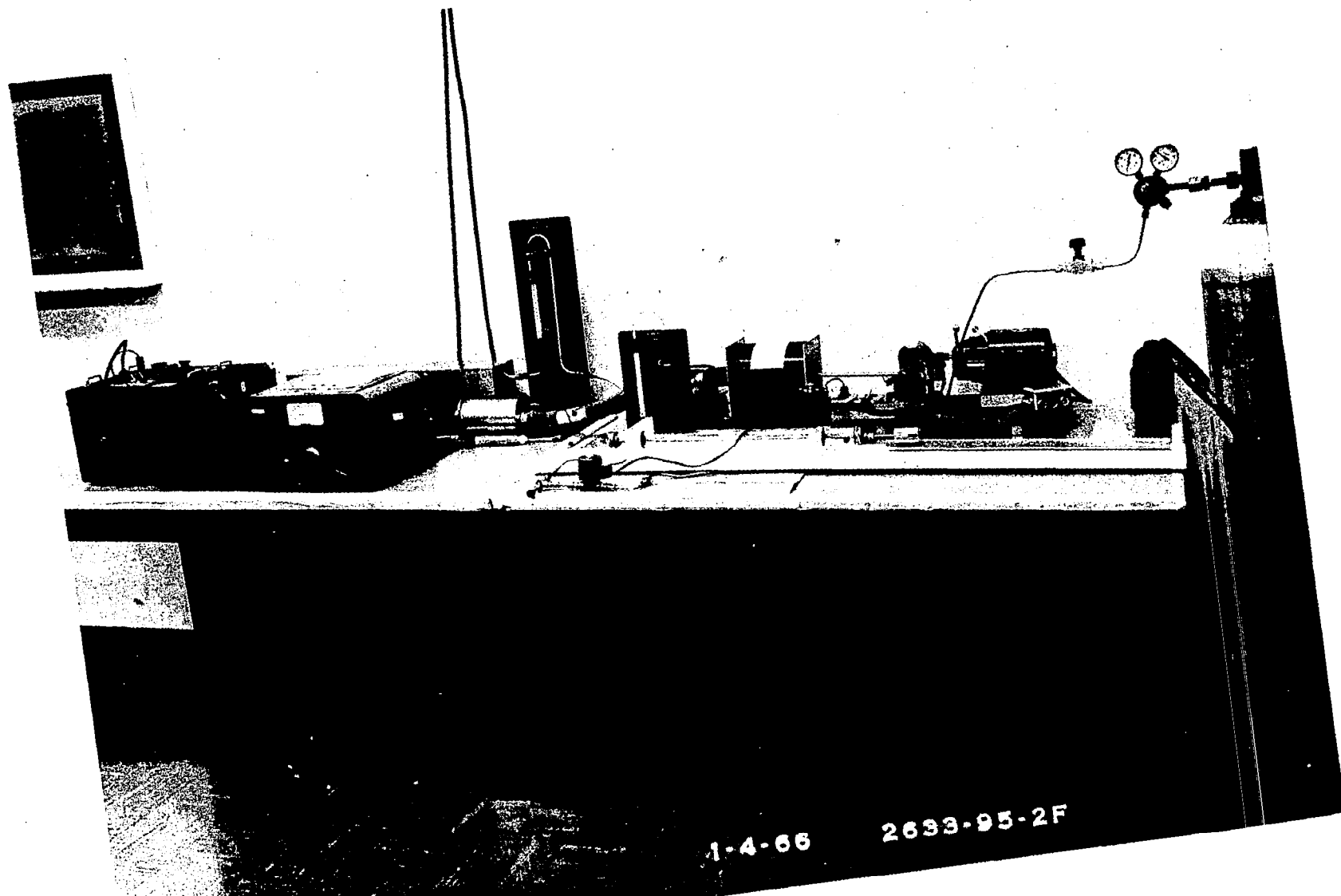
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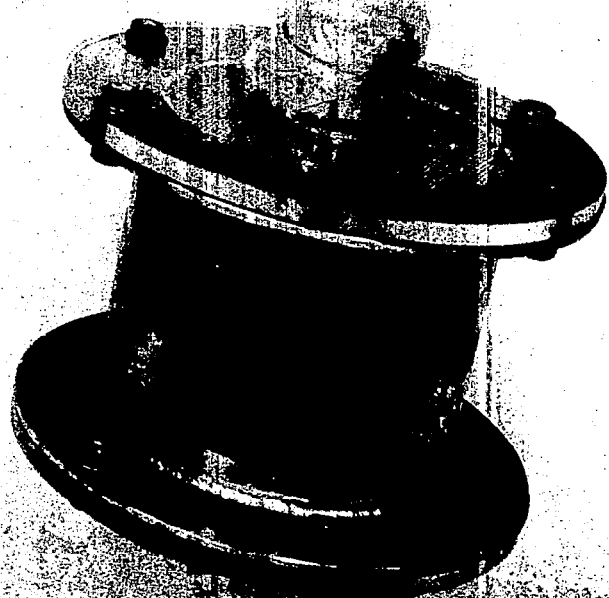
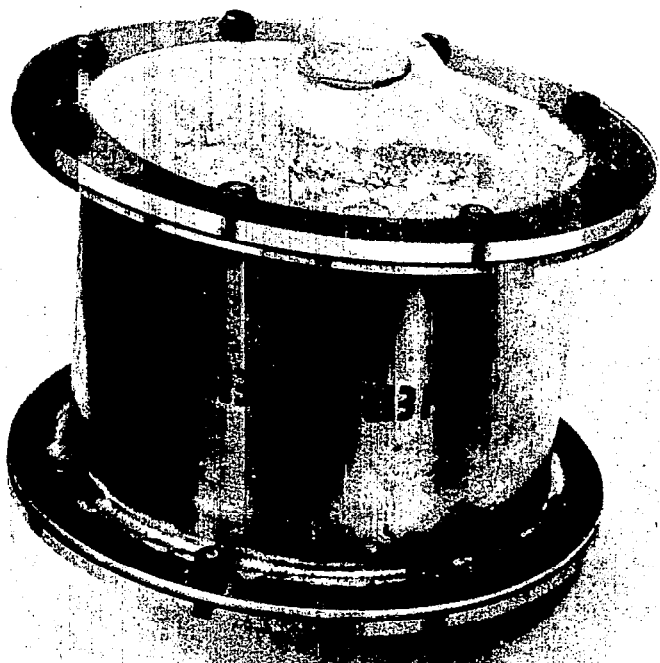
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